NOVEMBER 1957

THE WELDING JOURNAL

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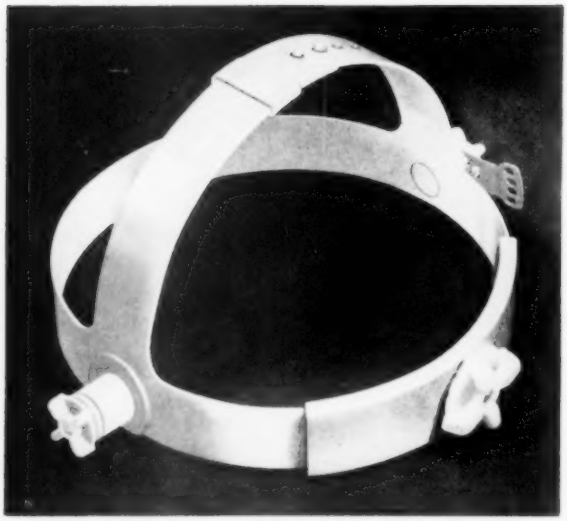

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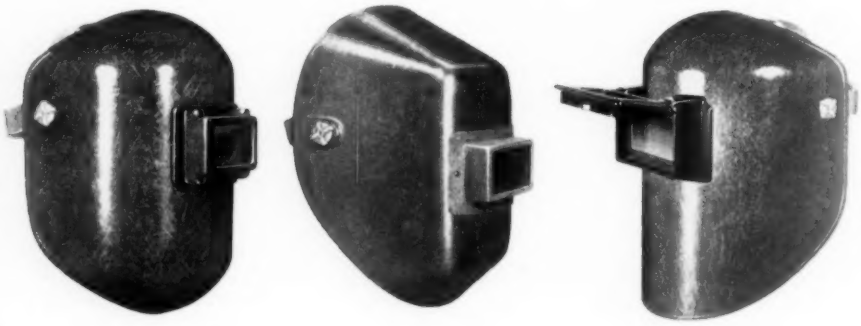

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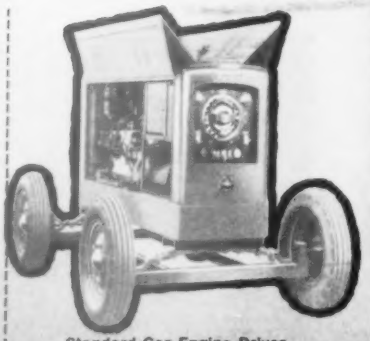

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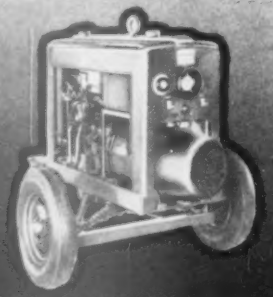

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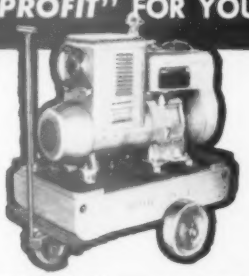

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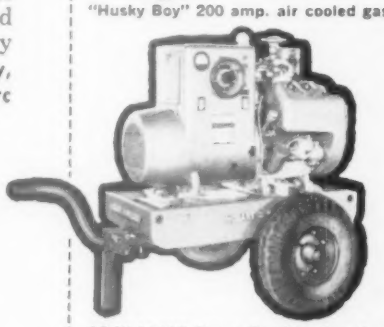

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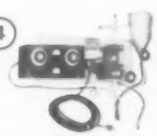

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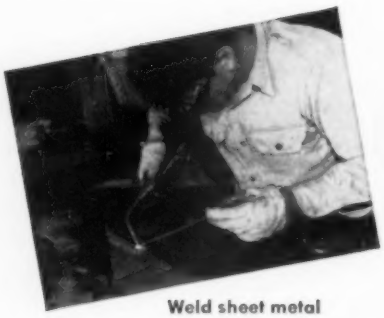

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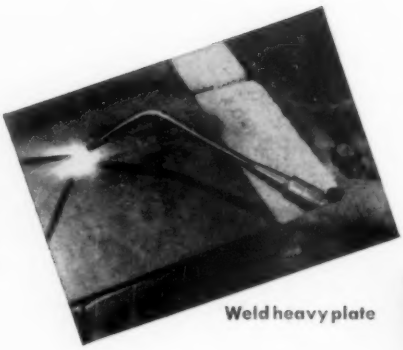

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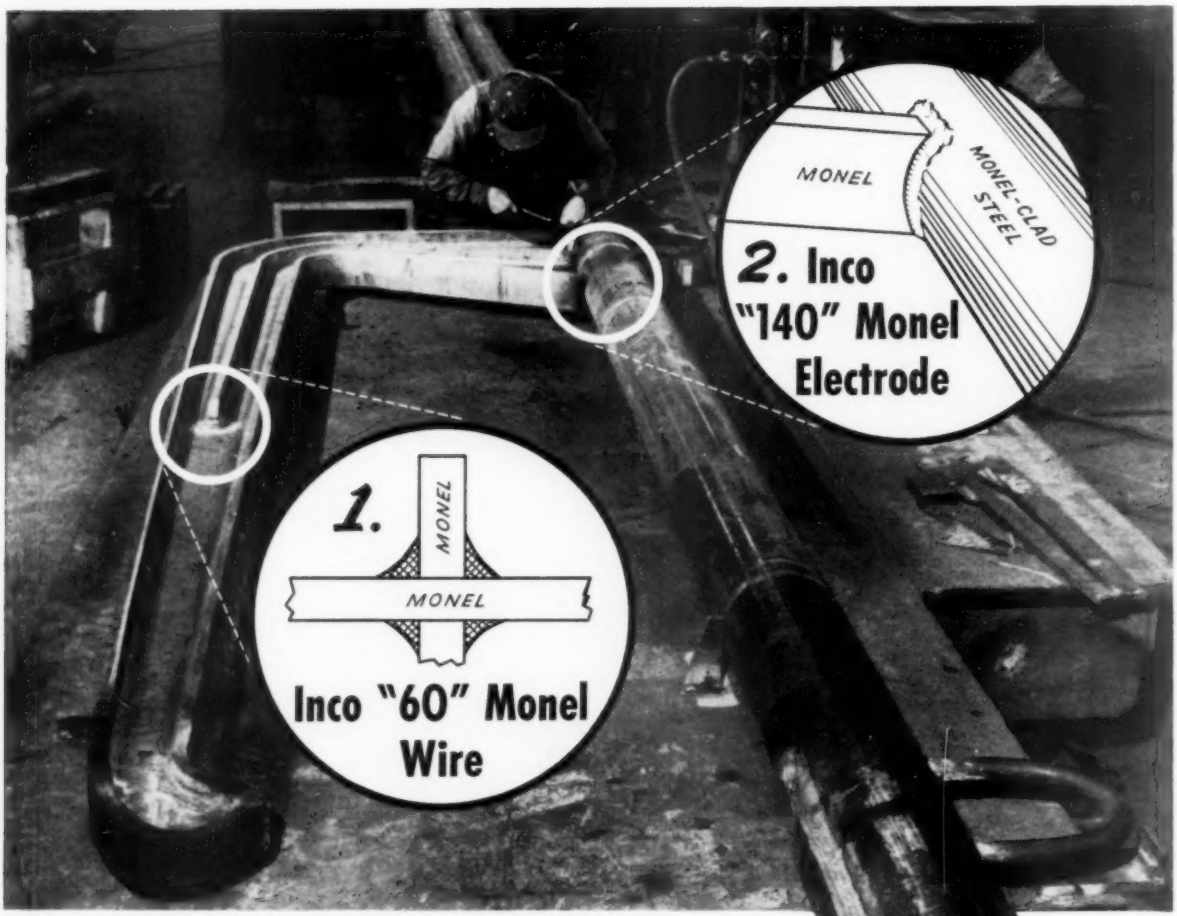

GIANT HAIRPIN PICKLING HOOK deflects only 2 inches under 2½-ton load. The Youngstown Welding and Engineering Company fabricates hooks of Monel; beams of Monel-sheathed steel. "60" Monel wire and "140" Monel electrode insure reliable welds.

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Insert (1) shows how Youngstown welds a Monel support rib to the Monel I-beam hook. Here, "60" Monel* wire in an inert gas consumable electrode welding unit, proves a hard-to-beat combination for getting predictable weld quality on a production basis. No flux. No slag removal. No preheat necessary.

Insert (2) shows how the end of the Monel I-beam is joined to the Monel-sheathed steel spreader beam. A different welding job. The I-beam must actually be welded to the steel beneath the sheathing. So Youngstown uses "140" Monel* electrode especially developed by Inco for metal-arc welding Monel to steel. It, too, gives predictable weld quality.

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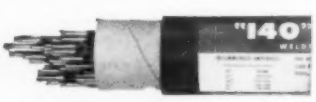

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EDITORIAL

COOPERATION IN WELDING RESEARCH

Current annual expenditures for research in the United States have been estimated to be about ten billion dollars. Although the individual still remains an important factor in research, today's teamwork approach is becoming more and more necessary in many research projects.

In this ever-widening research picture, an organization such as the Welding Research Council finds a logical and unique niche in the general scheme. The Council neither attempts, nor is expected, to produce spectacular "new products" or patentable discoveries. On the contrary, its strength and usefulness lie in other directions.

One of the most important functions of the Welding Research Council is educational. This educational activity covers various levels and specific fields.

The Council works closely with some thirty-five leading universities in the United States and Canada through researches by undergraduates, graduates, fellows and faculty. This educational work starts with the formulation of projects, development of hypotheses, discussions at committee meetings, planning of experimental work, analyses of experimental results and, after the results are obtained, their presentation in the form of papers before national meetings of Engineering Societies and publication of research reports. In a way, this is a continuous educational process. In this educational activity one of the most useful functions of the Council is fulfilled in the services of representatives of code-writing bodies on the project committees. This service results in their gradual education and acceptance and utilization of test results, thereby cutting to a small fraction the usual time lag between the production of results in the research laboratory and the general acceptance and utilization of these results by practicing engineers.

William Spraragen
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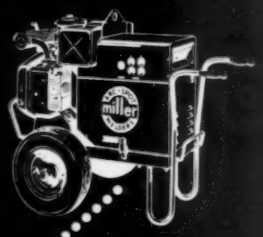

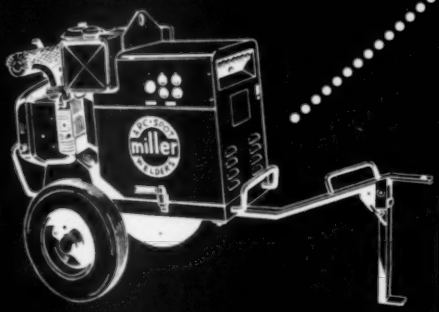

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A NEW CO_2 WELDING PROCESS

High deposition rate, a visible arc and sound weld metal are the principal advantages reported for new automatic CO_2 welding process which makes use of a bare flux-cored electrode

BY A. F. CHOUINARD AND R. P. MONROE

Introduction

The new CO_2 semiautomatic and automatic welding process for mild steel described in this paper is the result of a development program that had three specific objectives: (1) a high rate of metal deposition, (2) a visible arc, and (3) sound weld metal.

The first two were not hard to arrive at. The third—getting sound weld metal—presented obstacles.

The problem of porosity in weld metal is a familiar one in the welding industry. It is believed to be caused principally by carbon and oxygen, joining to form either carbon monoxide or carbon dioxide. The actual formation of these gases is not harmful. The harmful aspects are where they form, and at what time they form during the solidification of the molten metal.

Reports in welding literature lead to the conclusion that the gases combine at a temperature just above the solidification range, or freezing point, of the molten metal. If they form far enough below the surface of the freezing metal so that they cannot rise and escape from the surface, they become trapped and form porosity.

The solution to the problem was the introduction of materials into the molten metal that degasified it, that scavenged it, and at the same time protected the molten metal from the atmosphere.

The new process using a flux-cored electrode, achieves all

A. F. Chouinard is manager of Research and Development Department and **R. P. Monroe** is manager of Technical Service Department associated with National Cylinder Gas Co., Chicago, Ill.

Paper presented at the 1957 AWS National Spring Meeting, April 8th to 12th, Philadelphia, Pa.

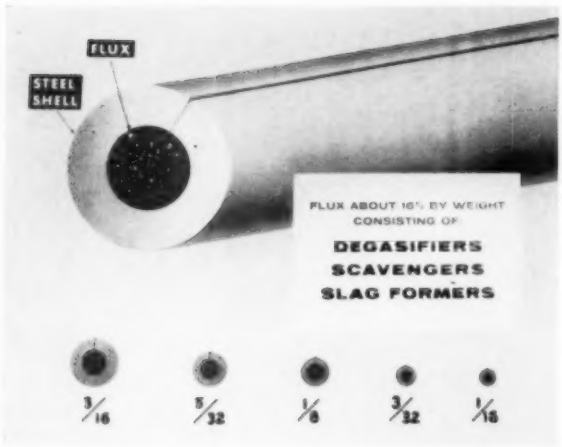


Fig. 1 Steel tubing is securely close together and contains flux filler

Fig. 2 Welding equipment used with flux-cored electrode process

three of its objectives—and does it without the usual excessive spatter that up to now has been associated with CO_2 welding processes. It also has other advantages.

Description of the Process

The process is similar to those that have found wide acceptance in the welding of stainless steels and nonferrous metals. Its salient feature is its ability to weld any type of mild steel, using CO_2 gas for shielding. The electrode is of special design and composition, and is fed through a semiautomatic gun, or automatic torch head, to the welding arc. Both arc and weld zone are blanketed by the atmosphere of CO_2 gas, which also is fed through the gun or the automatic electrode holder or torch.

The electrode is the key to the success of the process, as it controls the chemistry of the weld metal. The electrode is made by forming a steel strip into a cylindrical tube, and filling the interior with a specially prepared core material containing the degasifiers, scavengers and slag formers.

This process provides advantages over the usual types of bare wire, CO_2 gas-shielded welding processes, and retains the advantage of visibility of these processes. The submerged-arc processes hide the arc but provide good welds, while the usual CO_2 processes show the arc, but cannot provide some of the other desirable features. The new process has the best features of both; it permits operator to see where he is going and still provides a high grade weld.

Figure 1 shows an enlarged view of the steel tubing that is securely closed together and that contains the flux filler. The lower portion of the illustration shows the comparative sizes of the filler and the steel shell, and the sizes of welding electrodes now available.

This composite electrode is suitable for welding both killed and rimmed plain-carbon steel. The application of the electrode and the physical properties obtainable will be described later on. The least expensive shielding gas used in this process is carbon dioxide. The quantity used is simply the amount required to maintain a shield around the welding zone. The average is from 25 to 40 cu ft per hour. The quantity is not critical and the only restriction is that it should be welding grade CO_2 having a dewpoint of $-40°$ F or lower.

If argon or helium is used, the arc is *not* as smooth as when CO_2 is used. Argon or helium must be mixed with the proper amount of oxygen to obtain a smooth arc action. This is evidence that in the new process the flux materials in the core and the oxygen supplied by the CO_2 have been properly proportioned to produce smooth, quiet arc action.

The process has been developed for use with direct current, reverse polarity. Future development may permit the use of straight polarity or alternating current when a need for such modification appears.

Description of the Welding Equipment

The smaller electrode sizes up to $^3/_{32}$ in. diam may be used at currents up to 550 amp through the semiautomatic hand welding gun and the small automatic equipment. The larger electrode sizes must be used with the heavier duty automatic equipment, due principally to the stiffness of the welding electrodes.

The equipment used in this operation is similar in size and shape to the equipment used in the welding of aluminum and stainless steel, and is shown in Fig. 2. Both the manual gun and the automatic welding head

are water-cooled to withstand the high heats developed during welding. A dial on the side of the manual gun controls the feed rate of the electrode and may be adjusted during the welding operation. Once the speed of the feed wire is set, it is controlled automatically by only one thyratron tube. The feed rate of the electrode is not dependent upon arc voltage or arc current but is set independently by the operator for the correct operational speed required. The trigger on the gun is a latching type, and controls the starting and stopping of the welding operation.

The gas cups are specially designed to insure that the shielding gas does not interfere with the arc.

The circuitry of the manual gun control is arranged to provide touch starts. It is only necessary to have the wire projecting about $^3/_8$ in. from the cup of the welding gun and touch it to the work, then the following actions take place: (1) the shielding gas and water start to flow, (2) the previously chosen welding current burns off the electrode, and (3) the wire feed motor starts and feeds the electrode to the arc at the pre-set speed.

The operator needs only to move the welding gun at the correct speed along the joint. When the weld is completed, he simply pushes the trigger on the gun to stop the weld. An additional control predetermines the length of the electrode extending from the cup after each weld.

The constant-potential direct-current supply is best suited to this operation. Once the proper settings of the equipment have been made, a reasonably wide range of welding voltages may exist across the arc without having them seriously vary the current supplied to the welding arc. The welding machines used with this equipment are of the rectifier type.

Table 1—Process Variables

Electrode feed	60 to 600 in./min
Torch travel speed	20 to 100 in./min
Welding current	200 to 1200 amp
Welding voltage	20 to 35 volts
Rate of metal deposition	10 to 50 lb/hr
Current density	90 to 74 ka/sq in.

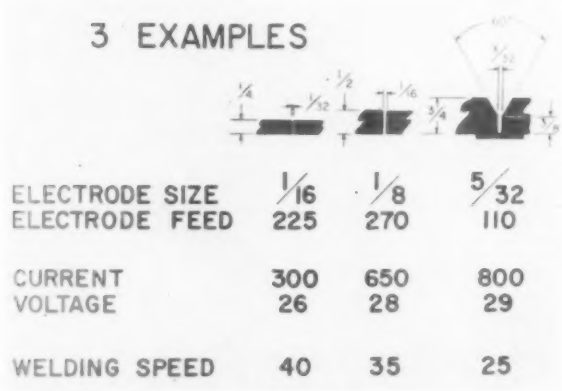


Fig. 3 Welding data for plate thickness from $^1/_4$ to $^3/_4$ in.

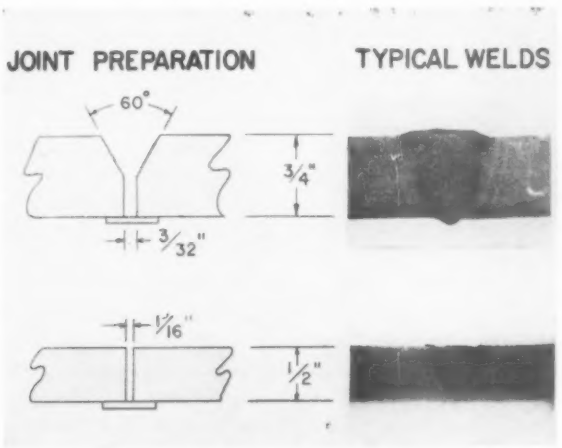


Fig. 4 Positioning of plates before welding and cross section of weldss

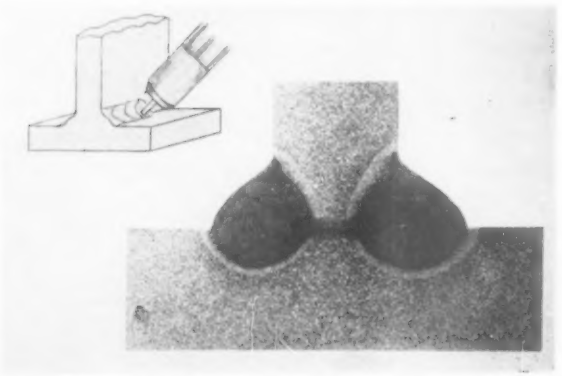


Fig. 5 Typical fillet-weld cross sections

Range of Process Variables

As in most welding processes, the welding current and voltage may be adjusted over a wide range, and in the case of continuous electrode welding, the wire feed speed can also be adjusted.

These are illustrated in Table 1, which indicates the range of these variables.

The chart shows the wide range of adjustment available with the different sizes of electrodes that can be used with this process, and specific examples for a number of single pass welds are shown in Fig. 3. It may be observed that there is some variation of the current density per unit cross-sectional area of electrode in this process. This is to be expected as the current density decreases with increasing cross-sectional area of the electrode.

Figure 3 shows actual welding data for plate thicknesses from $^1/_4$ to $^1/_2$ in. The data also show that the arc voltages are relatively low. The last line contains the important information: how fast the weld metal is deposited. It shows that the welding speed on $^1/_4$-in. plate is 40 ipm, or almost $3^1/_2$ fpm.

Figure 4 shows photos of cross sections of welds, together with the positioning of these plates before welding. The degree of penetration, the contours of the weld deposits, and the shape of the weld cross sections can be seen in these views.

It is interesting to note the contour of a fillet weld produced by this process. This is shown in Fig. 5. Note that there is no evidence of undercutting.

Applications of the Process

The electrode has not yet been developed for vertical or overhead welding. Nearly all of the welding is done in the flat or horizontal position.

Most types of joints may be welded by this process. Butt welds, lap welds and fillet welds are easily made.

The electrode is suitable for the welding of low- to medium-carbon steels and has even been used satisfactorily for welding steels up to one percent manganese and up to one-half percent chrome, and one percent molybdenum. Since these materials are used as alloying elements in T-1 and A202 steels, such steels may also be welded satisfactorily.

The usable range of plate thicknesses that may be welded is from 10 gage up. Single-pass welds may be made in plate thicknesses up to $^3/_4$ in. using $^3/_{16}$-in. electrode.

No special preparation either on the surface or the edge of the plate is necessary prior to welding. Conventional preparation is all that is necessary, and some scale and rust can be tolerated without adverse effects on the soundness of the weld. It is also unnecessary to use preheat treatment on any of these materials; but certain materials that need postheat treatment for stress relieving show an improvement in physical properties.

The flux in the core of the electrode shows up as a slag that covers the surface of the weld, both during and after the weld has cooled. The slag is relatively thin and it crackles as it begins to crack off during the cooling of the weld. It is not a tightly adhering slag. One quick stroke with a wire brush will not only loosen it but will practically sweep clean the entire surface of the weld.

In multiple-pass welding, it is necessary to clean this slag between passes, but its friability makes it easy to remove. Figure 6 shows how the slag comes away in large pieces. The slag has also been observed lifting away from many welds. This upward curling action is obviously due to the shrinkage on the upper, or cooler side of the slag.

Before the photograph for Fig. 6 was taken, the slag was loosened slightly. Some of the smooth surface of the weld can be seen.

Physical Properties of the Weld Metal

The important questions that are asked about any welding process are on the physical properties of the metal. No matter how simple it might be to weld the joint (and it *is* easy to weld a joint with this process), it still is necessary that the final result produce an acceptable weldment. One of the simplest ways to evaluate the usefulness of a new welding process is to compare the physical properties obtained with the new process to those obtained by a comparable manual electrode. These relative values may easily be compared in Table 2.

It can be seen that the values are similar to the values of the E6012 electrode.

Another advantage of this process will become apparent when it is considered for fillet welding. The strength of a fillet weld is determined by the cross-sectional area of the throat of the fillet.

A weld that has penetrated deep into the base metal will provide a larger throat area for a given size of fillet. Consequently, a smaller size fillet, that has this deep penetration, will produce a throat area having greater strength than a larger fillet that has less penetration.

An actual example in Fig. 7 shows the saving that is possible. Not only is deeper penetration obtained, but 43.7% of the weld metal normally required is saved. Not only is electrode material saved, but it can also be deposited faster.

Economics of the Flux-Cored Electrode

It was previously mentioned that the most important part of any welding process was its ability to produce an acceptable weld. Following closely on that consideration comes the question of how much it costs to produce it.

Two of the important cost figures are: (1) the cost of the electrode per pound, and (2) the cost of the electrode per pound after it has been deposited in a weldment.

The cost of this welding electrode as it is fed through the welding gun is 38¢ per lb.

The cost of this same electrode material after it has been deposited as weld metal is approximately 43¢ per lb of weld deposit.

The first price of 38¢ per lb is what is paid for the electrode as it comes on a 25-lb reel. Figure 1 showed that 16% of the electrode by weight was in the flux, so that the bare minimum of steel in the shell is 84%. However, some of the flux materials are alloying elements, and they raise the total amount of material that can be deposited to 90%.

It is this $^9/_{10}$ of a pound of welding electrode that costs 38¢, or on a 1-lb basis, it costs slightly less than 43¢ per lb for the material that goes into the weld.

It has also been found from tests that it costs about 43¢ to deposit 1 lb of weld metal. This is proof that the metal that *can* be deposited really ends up as weld metal. The spatter loss is also low in this process. Observation shows it and the cost figures prove it.

Table 2—Typical Mechanical Properties of Weld Metal (As Welded)

	Flux-cored electrode	*E6012*
	(Minimum values)	
Tensile strength, psi	74,000	76,500
Yield strength, psi	61,000	65,000
Elongation in 2 in., %	26.5	19
Reduction in area, %	59	35

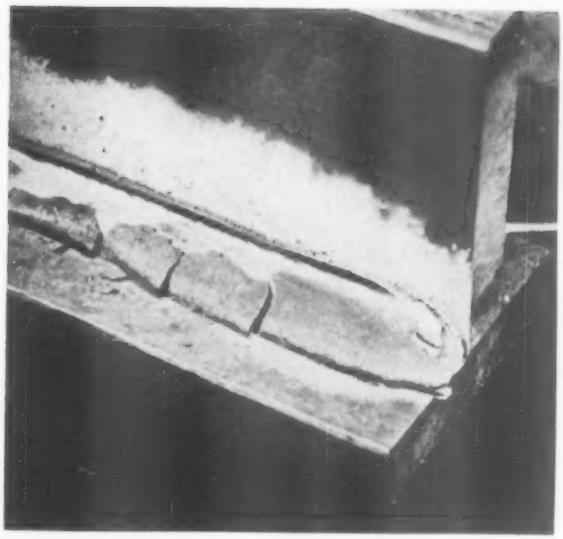


Fig. 6 Slag characteristics

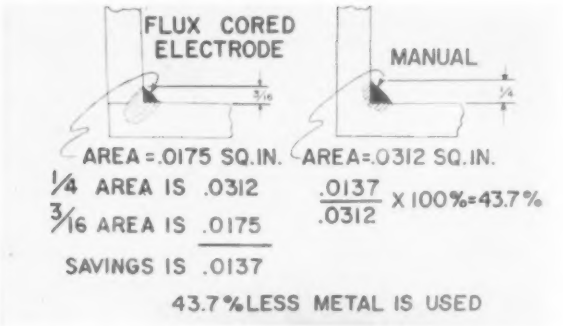


Fig. 7 Equal strength with less weld metal

As explained previously, the slag coating is quite friable and can be removed by wire brushing. With deposition efficiency high and spatter loss low, the clean-up is simply one of a general scratch brushing over the work.

One more statement about the cost of this electrode will be helpful in evaluating it. The cost per pound is not really the important cost, but rather the important cost is the cost of the entire weldment. When it is found that the cost of the completed weldment is less with this process, the exact cost of the electrode will not be important.

Examples

The total cost per lineal foot of welding is dependent upon so many variables, in different shops, that any actual cost figures would give no clues as to the savings that could be obtained with this process.

Consequently, the best way to illustrate the magnitude of the savings that are possible with this process is with a comparison chart as shown in Fig. 8.

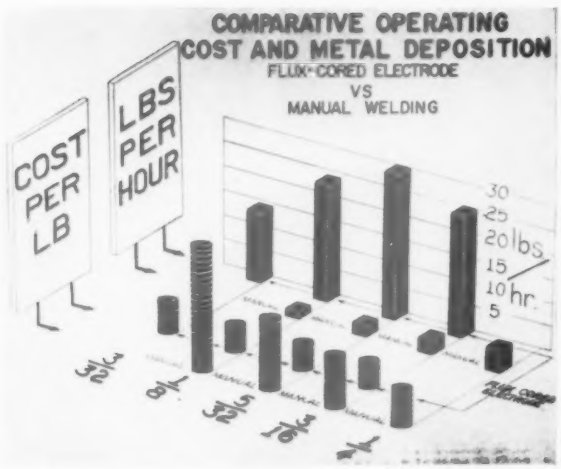


Fig. 8 Comparative operating cost and metal deposition for flux-cored electrode and manual welding

This chart shows the comparison between manual and semiautomatic electrode welding. The comparison is made for four sizes of electrodes, and it compares two important values: (1) the pounds per hour that may be deposited by each method of welding, and (2) the average cost per pound by each process.

These relative data are based on practical considerations, and are based on a 60% duty cycle.

The chart shows how much more weld metal may be deposited by the new process. This is shown by the height of the bars at the rear of the chart. In the front of the chart, a comparison is made between the cost per pound to deposit weld metal by each process.

It is rather obvious that when so much more metal is deposited during the same length of time, the unit cost per pound will drop. Figure 8 shows how much this saving can actually amount to.

Summary

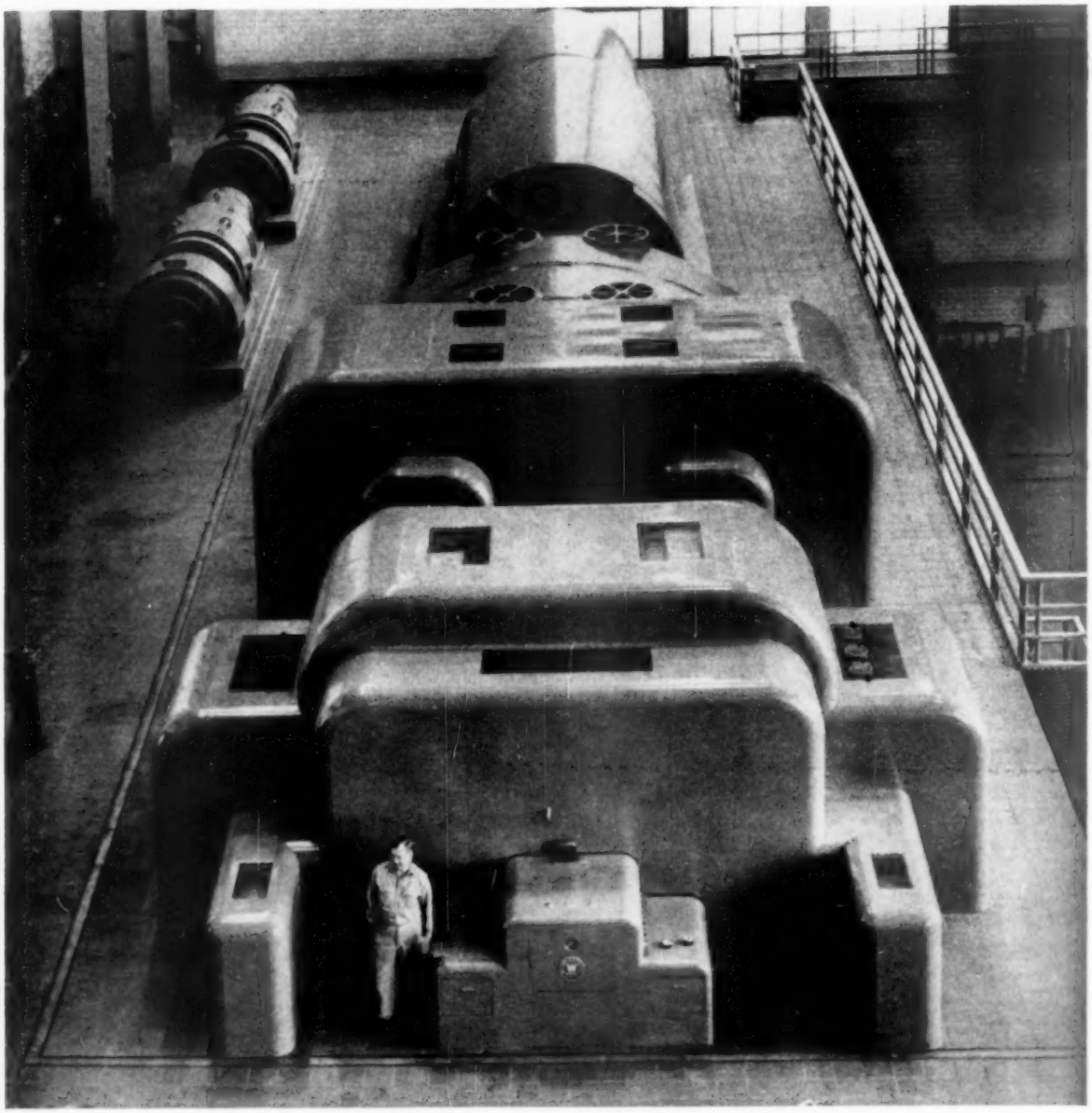
This new automatic CO_2 welding process using a bare flux-cored electrode has achieved three principal objectives: (1) high deposition rate, (2) a visible arc, and (3) sound weld metal.

It is suitable for welding low- to medium-carbon steels and has been used with good results on certain alloy steels.

Physical properties are equal to or higher than E6012 values.

Comparison tests with manual stick-electrode welding indicate that the new process, with semiautomatic equipment, deposits weld metal at a rate three to twelve times faster.

The process is used with semiautomatic and automatic equipment. The current is dc, reverse polarity, supplied by a constant potential type of rectifier welding machine.



Modern turbine-generator unit (200,000 kw) utilizes transition welds at main steam inlets

BUTT WELDING AUSTENITIC STAINLESS STEEL TO FERRITIC STEEL IN CYLINDRICAL SHAPES

Long-time exposure at actual operating conditions (850 and 1025°F) indicates no detrimental effects on properly made and properly applied austenitic-ferritic butt welds

BY J. E. DONAHUE

ABSTRACT. The use of austenitic steels in the high-temperature parts of several modern central-station turbines necessitates a transition from austenitic to ferritic steels. Several methods of accomplishing this transition have been used in the industry with varying success and varying acceptance.[1-5] This paper

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describes the design and the manufacturing techniques used by the author's company to produce certain transition pieces vital to the successful operation of a modern central-station steam turbine. These transition pieces are formed by a carefully controlled butt weld between austenitic and ferritic steels. Sizes vary from 1-in. Schedule 160 pipe to the equivalent of 16-in. Schedule 100 pipe.

Nomenclature

$\beta = 1.285/\sqrt{rh}$ = Beam on elastic foundation function for thin cylinders
r = Mean radius of pipe
h = Thickness of pipe
x = Distance along pipe axis from austenitic-ferritic junction
σ_t = Tangential stress
τ = Shear stress
σ_b = Bending stress
E = Modulus of elasticity in tension and compression
T_1 = Temperature at which transition weld is fully stress relieved
T_2 = Temperature at which stress is computed
α_1 = Coefficient of expansion of austenitic steel at stress-relieved temperature
α_2 = Coefficient of expansion of ferritic steel at stress-relieved temperature
μ = Poisson's ratio
k = Modulus of foundation for beams on an elastic foundation

General Description

Figure 1 shows the basic construction used in the six austenitic turbines shipped by the author's company to date. The steam-inlet sleeves are austenitic as are the separate nozzle chambers. The turbine outer casings as well as the inner casings are, however, ferritic steel. A section taken through the centerline of the steam-inlet sleeves would reveal three inlet sleeves and three separate nozzle chambers in both the cover and the base of each turbine. Thus there are 12 transition welds in each turbine for a total of 72 transition welds in vital locations.

Each transition weld is designed and manufactured to meet exact requirements. Once these requirements are established, however, the care in the design and manufacture becomes almost routine. The basic approach used in the design of the transition welds has been to:

1. Make the transition weld as a butt weld in a separate spool piece (called a transition piece) using downhand welding and good shop-control techniques.

2. Make this spool piece constant thickness at least at the transition weld; that is, avoid physical shape discontinuities at the transition weld, if possible.

3. Select an annealing temperature for the transition weld that is compatible with the eventual operating conditions.

4. Provide extra wall thickness to allow for a finishing turn (OD) and a finishing bore (ID) after annealing of the transition piece. This removes any imperfections in the root of the weld as well as any undercuts, crowns and or dendrites associated with the outside diameter of the weld. Thus, the transition weld is free of mechanical stress concentrations.

5. Make the usual X-ray, zyglo, etc., tests of the transition weld after machining of the transition piece.

6. Use sufficient length in the transition piece on each side of the transition weld. This is necessary to provide the flexibility needed to absorb the differential growth in diameter at the transition weld. It also assures that the subsequent ferritic-to-ferritic weldment and the subsequent austenitic-to-austenitic weldment at the ends of each transition piece are unaffected by the discontinuity at the transition weld. Thus the weldments at the ends of the transition piece, which may be in locations less than ideal, are not subjected to additional loading from the transition weld.

In essence, then, the design produces a transition weld free of mechanical stress-concentration factors, in a piece sufficiently long to provide adequate flexibility for absorbing the differential diameter growth. The length of the piece can be established using the theory for beam on an elastic foundation design.[6] This theory demonstrates that the longitudinal bending stress, the average tangential (circumferential) stress and the direct shear stress caused by the differential expansion at the transition weld dampen out in a wave-form pattern along the longitudinal axis of the pipe. Figure 2 shows that when βx equals π, the discontinuity effect is, for all practical purposes, completely dampened out. Once the diameter and wall thickness needed to meet the design requirements (such as ASA B31.1 Code for Pressure Piping) for the ferritic half are established, the austenitic half arbitrarily can be made the same thickness. The length of the transition piece each side of the transition weld is determined by utilizing Fig. 2. While ideal design calls for a βx function equal to π, the author's company, in general, has worked to a βx equals approximately 0.7π rule. This saves on overall length of the transition piece and yet it seems to provide adequate protection against the possibility of the discontinuity effects which are not yet completely dampened out, producing excessive stress in the ferritic-to-ferritic and the austenitic-to-austenitic butt welds at the ends of the transition piece.

The actual stress caused by the discontinuity at the transition weld can be calculated by utilizing the theory

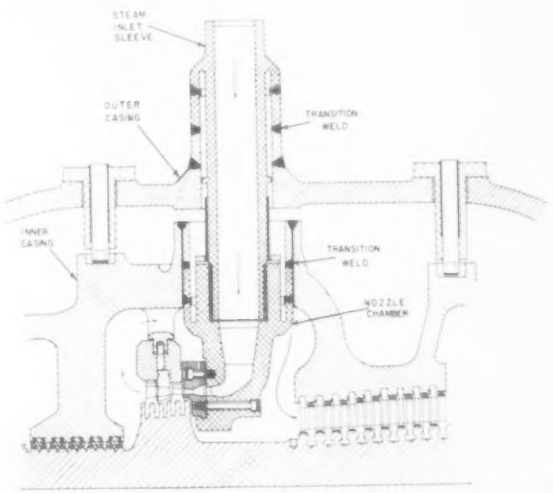

Fig. 1 Turbine longitudinal section with transition welds in place

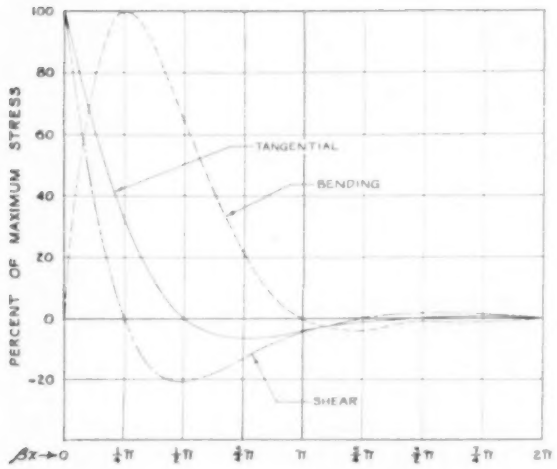

Fig. 2 Stress-distribution pattern at transition weld

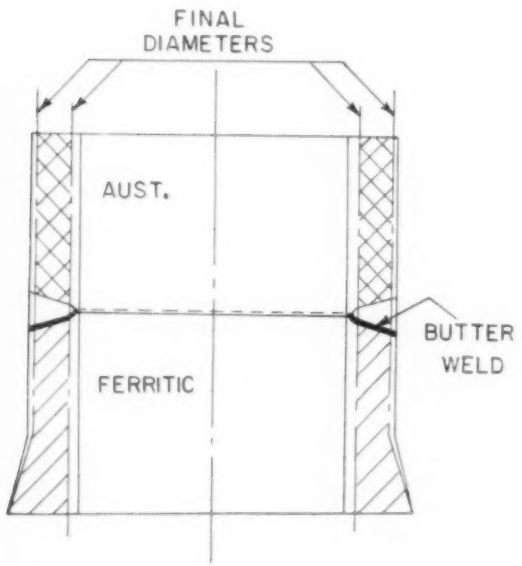

Fig. 3 Detail of transition weld

for beams on an elastic foundation (refer to the Appendix).

With reference to Fig. 2, note that the stress coefficient is unity for both the tangential (circumferential) stress and the direct shear stress at βx equals zero. Thus these stresses are maximum right at the transition weld and dampen out along the axis of the pipe as per Fig. 2. The maximum values of these stresses in psi are

$$\sigma_t = (0.5)\ (E)\ (T_1 - T_2)\ (\alpha_1 - \alpha_2) \qquad 1^*$$

$$\tau = (0.19)\ (E)\ (T_1 - T_2)\ (\alpha_1 - \alpha_2)\sqrt{h\ r} \qquad 2^*$$

The longitudinal bending stress is zero (refer to Fig. 2) at the transition weld, builds up to a maximum at βx equals $\pi/4$ and then dampens out along the axis of the pipe. The maximum value of this stress in psi is

$$\sigma_b = (0.29)\ (E)\ (T_1 - T_2)\ (\alpha_1 - \alpha_2) \qquad 3^*$$

For an assembly that is fully stress relieved at 1350° F, the calculated stresses at an operating temperature of 1050° F are rather nominal. At room temperature, these calculated stresses are of an appreciable magnitude. It should be recognized, however, that:

(*a*) As published in Section 6, Chapter 3, of the recent ASA-B31.1-1955 Code for Pressure Piping, it is the stress range and not the magnitude of stress at any instant which is governing in this type of design loading.

(*b*) Stress relieving the transition piece by itself assures that the stress-range terminal strain will be a maximum at room temperature and a minimum at operating temperature. Thus the pressure strains, the thermal gradient strains, the external loading strains, etc., normally superimposed during operation of the turbine are superimposed on a minimum locked-up strain in the transition piece for even the first cycle of the installation.

(*c*) Many different investigations have established that loadings of the cyclic thermal-expansion type can impose strain ranges equivalent to twice the yield-point strain and yet not produce a failure until many thousands of cycles have elapsed.

* Refer to the Appendix for discussion of limitations of these formulas.

Table 1—Manufacturing Data on 72 Transition Welds*

No. welds made	*Austenitic side ASTM*	*Ferritic side ASTM*	*Ferritic side Buttered*	*Preheat ferritic side only*	*Furnace anneal†*	*Weld rod‡*
30	Type 347	A-335-P22	24 Yes	6 at 600° F 6 at 450° F§ 12 at 450° F	1350° F	18 of Type 347 6 of Type 347M
			6 No	6—None	1300° F	6 of Type 347M
30	Type 347	A-335-P12	24 Yes	6 at 600° F 6 at 450° F§ 12 at 450° F	1350° F	18 of Type 347 6 of Type 347M
			6 No	6—None	1300° F	6 of Type 347M
12	Type 347	A-335-P22 W‖	12 No	12 at 450° F	1300° F	12 of Type 347M

* Half of these welds operate at 850° F approximately, the other half at 1025° F approximately.
† The difference in annealing temperature should not be viewed as significant.
‡ The weld rods designated Type 347M are a Type 347 rod with 3–5% controlled ferritic.
§ These 12 were preheated for the deposit of the ferritic butter weld only.
‖ This material is a Westinghouse Spec. Basically it is A-335-P22 with some Vanadium.

Figure 3 shows a typical transition piece. Note that an integral backing ring has been used for the transition weld. There is, however, no basic reason why a separate backing ring, or some other type of end preparation, could not have been used since the ID is machined after welding.

Table 1 lists some general information on the manufacture of the 72 transition welds in question.

The boiler-design characteristics, the features of the turbine design and the desirability on the part of the operators to keep these turbines working at full, or almost full, loads, probably means there is little or no thermal cycling of the transition welds except for actually stopping the turbine. Even here, however, these shutdown cycles do not represent, in all cases, full thermal cycles because of the time needed to cool the installation. Thus the actual operating history of these particular transition welds contributes mainly to the knowledge of "aging effects" and helps to develop confidence in their continued use at least for applications with operating conditions comparable to those of modern electric power stations. In this respect, it is known that the oldest transition welds have been in actual operation since December 1948. The author estimates that the number of temperature cycles of a full, or almost full, operating range on the most cycled welds is probably less than 100.

All of the 72 transition welds discussed have been of the same general order of size, that is, 10- to 16-in. OD with $^3/_4$- to 1-in. wall thickness. About 50 transition pieces in the 1-in. and $1^1/_4$-in., Schedule 160, nominal sizes also have been used in the steam drain lines of these turbines. Some difficulty was experienced in operation with a few of these drain-line transition pieces on one turbine. The difficulty was attributed to excessive thermal cycling.* A rearrangement of the drain lines to eliminate the excessive thermal cycling seems to have been successful. In fact, the rearrangement employs twice as many transition pieces as the original design, but with reduced thermal cycling. These drain-line transition pieces employ the butt weld machined on the OD and ID, etc. The ferritic-to-ferritic and austenitic-to-austenitic weldments at the ends are conventional socket welds into socket-weld fittings.

Conclusions

Long-time exposure at actual operating conditions, to date, has shown no detrimental effects on properly made and properly applied austenitic-ferritic butt welds. These operating conditions include pressure, temperature and external loadings such as the steam-inlet piping reactions and the nozzle-chamber reactions which are transmitted through transition welds to the outer turbine casing and the inner turbine casing, respectively. Admittedly, the number of full cycles, while reflecting actual power-plant operation, has been somewhat limited, but the extended periods of time at operating conditions do offer a valuable supplement to the test specimens and design theory discussed in the paper listed.[1–5]

Thus it would appear that direct austenitic to ferritic butt welds in today's conventional materials can be made in pipe shapes with assurance of complete operating success provided:

1. Manufacturing techniques of the general type discussed in this text to provide a transition weld free of all mechanical stress concentrations, with a full stress-relief at some temperature compatible with the operating temperature, are followed.

2. An adequate length of pipe x, each side of the transition weld, is provided before coming to any other welds and or rigid bodies; etc. This length can be determined from Fig. 2 as

$$\text{Minimum } x = \frac{0.7\pi}{\beta}$$

3. The number of full temperature cycles over a wide temperature range is limited; that is, of the order of thousands of cycles rather than tens of thousands. Obviously, the smaller the temperature range, the more cycles of life that can be expected. Also, cycling of a repetitive quenching type should be avoided.

Appendix

For a pipe which is a thin-wall cylinder, the deformation (unequal radial expansion) at the transition weld is symmetrical with respect to the pipe axis. A longitudinal strip of unit width can be investigated. The discontinuity effects at the transition weld are distributed along the strip in proportion to the distortion at every section along the strip. Since this is the criterion for a beam on an elastic foundation, the strip may be analyzed as a semi-infinite beam on an elastic foundation with $k = Eh\ r^2$ from which the term β can be established as $\beta = 1.285/\sqrt{rh}$.

J. D. Conrad† in his discussion of the Weisberg paper[1] develops the formulas for σ_l, τ and σ_b as well as the plot of Fig. 2 used in the text of this paper. For simplicity, his development assumes that at the operating temperatures of the piece, E and μ are for all practical purposes the same for both the austenitic half and the ferritic half. Otherwise, the formulas must be modified to suit. Similarly, the radius used in the β-term to determine the desirable design length each side of the transition weld should be modified when the pipe is not of constant radius, as for example, a conical length of pipe.

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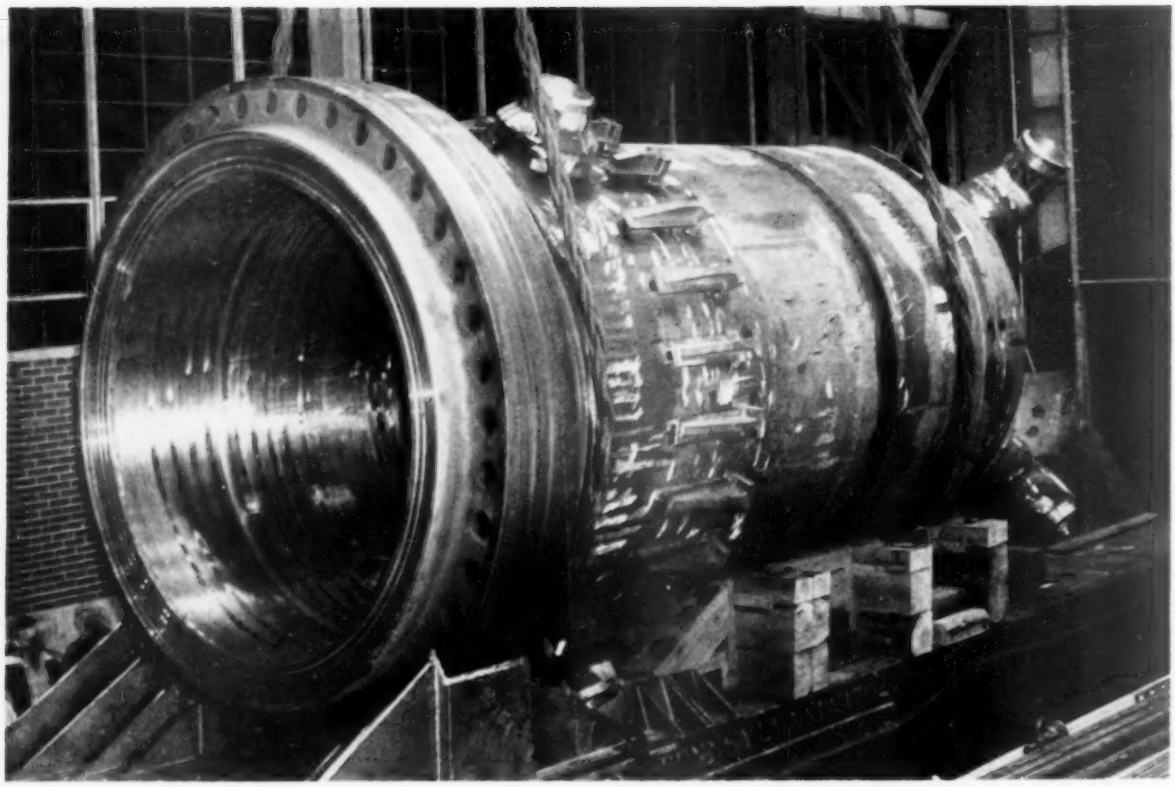
* This cycling was a repetitive quenching type.

† Assistant Manager of Engineering, Westinghouse Electric Corp., Steam Division, Philadelphia, Pa. Mem. ASME.



Shell for nuclear reactor showing internal stainless-steel cladding deposited by submerged-arc process underneath bonded flux

BONDED FLUXES FOR SUBMERGED-ARC WELDING OF ALLOY STEELS

New-type flux is described as permitting the controlled variation of weld chemistry through incorporation in the flux of alloying elements, deoxidizers and strong fluxing agents

BY HALLOCK C. CAMPBELL AND WALLACE C. JOHNSON

Introduction

A new kind of submerged-arc welding flux with highly interesting properties has recently entered the automatic welding field. Because the ingredients are bonded together at an unusually low maturing temperature, great versatility of formulation is possible. As a result, several different types of flux have been developed, each one designed for some specific application.

Typical Properties

In the field of stainless steels, one type of flux is successfully welding a wide variety of compositions. This flux when used with regularly available filler metals, such as Type 308, gives the same analysis that would be expected from covered arc-welding electrodes made from the same core wire. Thus, if the heat of wire is rich in ferrite, the submerged-arc deposit is also rich in ferrite. However, the flux can be modified to alter the weld composition, in much the same way that a manufacturer modifies a manual electrode covering to produce special weld metal compositions and properties. A striking example is a stainless weld with low magnetic permeability made from standard-composition core wires, by using a purposely modified flux.

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Good slag removal from stainless-steel welds has been achieved, a property which has been long desired but seldom available in submerged-arc welding.

Low-alloy steels are being welded under bonded fluxes containing alloying elements or special deoxidizers. Several applications are mentioned hereafter, in which clean, sound welds were the prime consideration. Freedom from slag entrapment, and the desired high-tensile and impact properties were assured by the special fluxes developed for this work. It is expected that many of the new alloy steels will prove to be weldable with standard filler wires, by using fluxes reinforced with the necessary powdered alloys.

Color identification of these various fluxes is well established. This is a far reaching development, as the existence of many versions of each fundamental flux would lead to errors in application were it not possible to give each type a distinctive color, such as can be done with these bonded fluxes.

A pronounced wetting action has been observed with some of these fluxes. Welding tests on a laboratory scale have indicated the possibility of using a narrow groove design for butt welding. The narrower groove would be usable because of the wall-washing or climbing action of the weld metal under the flux, giving a concave bead with easy slag removal, which permits fewer split passes.

At the present writing, since numerous applications in the fields of stainless and low-alloy welding are in progress, it seems appropriate to make a report on this new development.

Previous Fluxes

Conventional submerged-arc welding fluxes do an excellent job on the normal low-carbon steels, but they have many limitations when it comes to welding the many varieties of low-alloy and stainless steels. The high physical properties of the newer low-alloy steels are difficult for the older fluxes to meet; better deoxidation of the deposits and more closely controlled additions of alloying elements are usually needed. In stainless welding, the difficult slag removal and off-balance chemistry of conventional submerged-arc welds have discouraged most fabricators from attempting to use this much faster method of welding.

Unfortunately, due to the way they are made the conventional fluxes cannot be efficiently modified to offset these defects, which therefore limit their application to the unalloyed steels. There are two types of conventional flux, a fully fused type and an agglomerated type. Both of these are heated to such a high temperature at some stage of their manufacture that powdered alloys or deoxidizers cannot be retained in a useful form. As taught by several American patents, some of which have now expired, the fused type of flux is made by heating various minerals to approximately 2500° F. At this temperature, the ingredients melt together to form a glass which is then crushed and screened to form the granular welding material. The agglomerated fluxes, according to the patents and published technical explanations which are part of our welding literature, are held together by a ceramic binder, which must be heated to a temperature ranging from 1400 to 1800° F.

At these high temperatures, the deoxidizers which are generally used in arc-welding electrode coatings, such as ferrosilicon, ferromanganese, ferrotitanium, usually become oxidized well beyond their most effective usefulness. While the desired addition of silicon or manganese to the weld deposit can be achieved to a large degree through chemical equilibrium, which is established by slag-metal interaction, a rapid deoxidation of the weld pool is usually not possible. Some of the more effective deoxidizers, which melt well below 1300° F, cannot be used at all in either of the two types of conventional submerged-arc flux.

Bonded Fluxes

By borrowing from well-established techniques used in making extruded electrodes, the new bonded type of flux has been developed. Because of the novel features of various fluxes of this type, several patents have been applied for, claiming unusual properties obtained by the unique bonding method.

These fluxes mature at drastically lower temperatures than those used for the conventional fluxes, which is therefore one of their main differences, and the source of most of the advantages obtained through their use. Low-temperature baking, at half the usual temperature, permits adding ferroalloys to the flux without fear that they will become oxidized as they are bonded. The raw materials and alloys are carefully selected from purified materials, and fully mixed before baking. This produces a uniformly alloyed flux capable of adjusting the composition of the deposited weld metal to compensate for any elements that may be lacking in the chemistry of the filler wire. Examples are given hereafter in connection with the description of several stainless-steel applications.

In spite of the low maturing temperature, the flux components are firmly bonded together within the granules. The ability of the particles to withstand repeated handling and the temperature changes related to blanketing the fused slag was convincingly demonstrated by one large user, who kept track of a single lot of flux during 20 cycles through his flux recovery and welding system. No appreciable change in the particle size was detected in this exaggerated test.

The low baking temperature also permits incorporating ceramic colors in the bonded flux for identification purposes. This has been nearly impossible to do in the case of the fused and the agglomerated processes. A green color is being used for the fluxes now available for welding low-alloy steels; a gray color is used for stainless-steel fluxes; and a red color identifies alloy-enriched fluxes designed to reinforce the weld deposit over and beyond the composition limits of the filler metal or base metal involved in a particular application. These colors are a permanent attribute of each flux, as they are bonded into each of the granules. They are not changed by the welding heat until fused into the

Fig. 1 Self-removing slag curling up from Type 308 weld bead deposited on Type 304 plate

Inverted specimen of slag shows functional secondary layer formed at metal-slag interface

slag, which as with all fluxes is discarded. The bright identifying color helps to insure that the operator is using the right flux, and also serves to indicate whether the flux has become mixed with other fluxes, or with dirt or oil.

Bonded fluxes are not entirely insensitive to atmospheric moisture. In humid areas of the country large users have been careful to keep the flux dry and warm, and one of them at least has found it helpful to use a heated hopper at the welding head. Fortunately, the moisture absorbed from the atmosphere by the flux is readily driven off by rebaking at 400° F for about an hour.

Improved Slag Removal

The avoidance of all fusion during the making of the stainless-steel fluxes permits incorporating minerals which greatly improve the removal of the slag. Until recently, very little stainless steel has been welded by the submerged-arc process, for two reasons. First, the older fluxes did not compensate for the loss of chromium and other elements which occurred across the arc; in fact, an appreciable portion of the chromium was always oxidized and absorbed into the molten slag. Second, the fused flux or slag has usually stuck so tightly to the cooling weld metal that it has been very hard to remove it. Many fabricators found that it was taking the operator more time to fully remove the slag than it did to run each welding pass in a multiple-pass butt weld or heavy overlay.

The chromium loss can be decreased by adjusting the basicity of flux (through choice of the proper component minerals); or it can be compensated for by adding ferrochromium or chromium metal to the bonded flux. Both of these principles have been applied in the case of one of the gray fluxes now on the market.

However, since the commonly used minerals and slag-forming materials, when melted, will adhere tightly to all stainless welds, the development of a flux with good slag removal required considerable study. What resulted was a flux which formed, at the interface between the slag and the metal, a secondary layer of a material which did not stick to the cooling weld. For this purpose a mineral is chosen whose coefficient of expansion is so different from that of the stainless steel that it forms a self-removing slag, which on cooling will actually curl away from the stainless weld. Figure 1 shows this self-removing slag, and also the pearl-gray secondary layer, which leaves the weld surface smooth and entirely free from residues of slag. This self-removing property makes it unnecessary to have the operator spend any of his time in removing clinging slag.

Modified Stainless Welds

The Navy nonmagnetic mine sweeper program has imposed special demands on the welding industry. The electrode manufacturers have been able to meet this need through electrode-coating modifications. Using the standard austenitic filler wires, it was not possible to duplicate such electrodes in the submerged-arc field until these alloyed fluxes became available. Now, by using fluxes reinforced with carbon, nickel and manganese, weld deposits with magnetic permeability below 1.2μ have been achieved by several fabricators.

A typical weldment is shown in Fig. 2.

The photograph shows the welding of a subassembly for an 8-cylinder V-type diesel-engine frame. When the manual welding of these diesel engines was reported* at the AWS 1955 Fall Meeting, the authors pointed out that submerged-arc tests had been only partially successful up to that time. It will be recalled that the solution of the manual arc-welding problem was the development of special high-carbon stainless-steel electrodes. The present successful application of submerged-arc welding resulted from the parallel development of a bonded flux which permitted increasing the carbon content of the deposit in order to control the ferrite-austenite balance. Automatic welding has proved to be not only faster than manual welding, but also applicable within spaces too small for a welder to crawl through or awkward to reach into, as illustrated by this diesel-engine subassembly.

Analytical data for stainless welds made with several bonded fluxes are shown in Table 1. For orientation, the table first gives the typical weld-deposit analyses for Type 308 and Type 309 compositions deposited under a "standard" bonded flux. The good recovery of chromium is to be noted. The loss of manganese

* Lang, John L., and Wright, Charles, "Permeability and Crack Sensitivity of Stainless Welds," THE WELDING JOURNAL, **35** (3), 225–228 (March 1956).

Table 1—Bonded Fluxes for Stainless-Steel Welds

	C	*Mn*	*Si*	*Cr*	*Ni*	*Permeability*
Type 308 filler wire analysis	0.04	1.70	0.35	19.98	10.08	
Nondilution weld deposits with three production fluxes welded at 28–30 v, 600 amp						
	0.05	1.33	0.77	19.47	10.17	
	0.05	1.36	0.70	19.36	9.94	
	0.05	1.33	0.61	19.51	10.01	
Type 309 filler wire analysis	0.10	1.83	0.56	24.70	13.98	
Nondilution weld deposits:						
Welded at 30 v, 250 amp	0.12	1.51	0.62	25.10	13.39	
Welded at 30 v, 600 amp	0.10	1.50	0.82	24.30	13.27	
Type 308 filler wire analysis	0.05	1.70	0.36	20.10	9.78	Over 2.0
Nonmagnetic deep groove welds:						
Flux 81	0.11	1.68	0.64	19.81	9.68	1.6–2.0
Flux 84	0.09	1.53	0.52	19.14	9.92	Below 1.2

	Yield strength, psi	*Tensile strength, psi*	*Elongation in 2 in., %*	*Reduction in area, %*
All-weld-metal 0.505-diam tension tests				
Welded with Flux 81	63,300	89,000	40	46
Welded with Flux 84	61,000	86,500	43	49

Fig. 2 Nonmagnetic subassembly for diesel-engine frame. Operator is welding Type 304 plates with Type 308 filler wire under special bonded flux

and the inevitable pickup in silicon are kept within satisfactory control limits.

The addition of high-carbon ferromanganese to this flux gave the nonmagnetic welds listed at the bottom of the table. The fluxes marked "81" and "84" in this table were experimentally developed for two different fabricators. The "84" flux, which had no chromium reinforcement, was later used by both fabricators because of its lower magnetic rating.

Low-Alloy Applications

The welding of low-alloy high-strength steels is being accomplished by several of the country's largest fabricators using fluxes of this new type. The most spectacular and exacting applications are those involving very heavy components for nuclear power installations, using plates up to 14 in. thick.

A cross section through a typical butt weld for one of these vessels is shown in Fig. 3. The weld was made under the welding conditions summarized in Table 2, using a bonded flux reinforced with sufficient manganese to keep the manganese in the weld at about the level in the filler wire. The tensile strength of the finished weld must be over 80,000 psi but without exceeding that value too much, as the weld must also have high notch ductility at +10° F. Modifications of this flux are expected to be applicable to future units, which may call for a different alloy-steel base metal.

Welded Overlays

Overlay welding, i.e., cladding by automatic welding, is a field in which bonded fluxes are finding many applications. The first pass is deposited with the series-arc technique, which permits holding the base-metal dilution to 10%. The most severe requirements to date have been those imposed by the welding of a heavy overlay or cladding on the 9-in. thick manganese-molybdenum steel cylinder, hemispherical heads, and tube sheet for a nuclear reactor. The lead photograph is a view of the 150-ton reactor shell, showing the stainless-steel cladding inside the heavy flange. The inside diameter of this shell is over 9 ft.

In the case of the tube-sheet overlay, an extremely sound weld was demanded by later machining and tube welding operations, which would be defective if even slight inclusions, pores or fissures were present in the original overlay weld. Repeated laboratory tests were made by the prime contractor in the process of developing the best welding procedure. Many weld sections were examined under the microscope and found to be clear and sound. When the tubes were welded in place by the tungsten-arc method (in an automatic sequence involving no filler metal) these tube welds were sound and free from cracks. When other commercial fluxes made with less active deoxidizers were used to make the same overlay weld, numerous inclusions and defects were encountered; these caused the tungsten-arc tube welds to "boil" and fissure, which made them unacceptable. Production operators qualified the process with the bonded flux by first making the heavy overlay weld, followed by about 100 tube welds with the tungsten-arc setup, with no rejections.

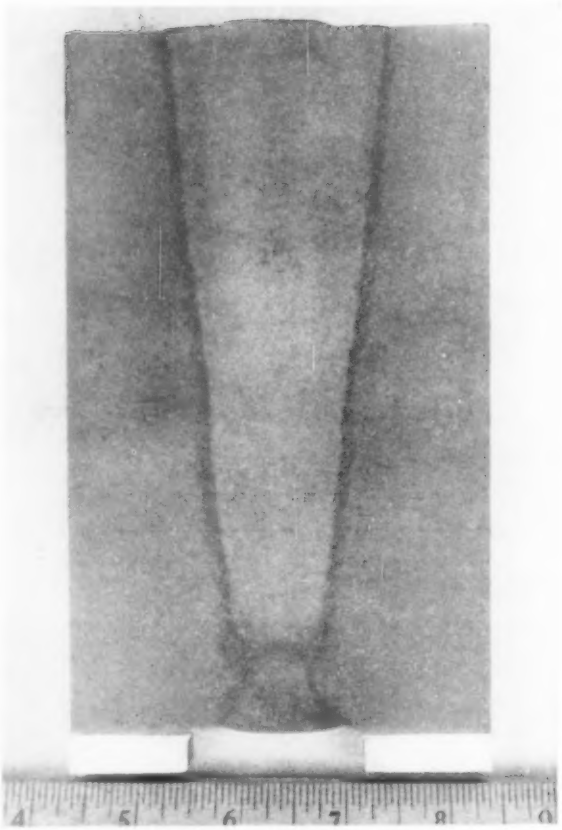

Fig. 3 Cross section through butt weld in 7-in. thick manganese-moly plate

The weld was made with $^5/_{32}$-in. Mn-Mo wire and a manganese-reinforced bonded flux, under the welding conditions given in Table 2

A similar application of submerged-arc overlay welding is illustrated in Fig. 4. This job was less critical than the nuclear job described above, and the series-arc overlay technique was used as a low-cost method of obtaining a $^3/_8$-in. thick corrosion-resistant surface. The base-metal parts are castings for a central station blade ring. The service will be steam atmosphere at not over 500° F. Whereas Type 309 filler wires,

Table 2

Base metal: Manganese-molybdenum steel, Type SA302 Grade B.

Filler wire: $^5/_{32}$ or $^3/_{16}$-in. diam MnMo (approximately 0.13 C, 1.95 Mn, 0.50 Mo).

Flux: Manganese-reinforced bonded flux.

Preheat: 300° F minimum; preferred range 400° min to 600° max.

Heat Treatment: 1200° F (1 hr per inch of thickness), slow heating and cooling cycle.

Typical welding sequence, after welding two root passes with manual-shielded metal arc:

Bead No.	*DC, Reverse polarity, amp*	*Volts*	*Travel, ipm*
3	375	30–32	15
4	500	30–32	11
5–117	550	30–32	11

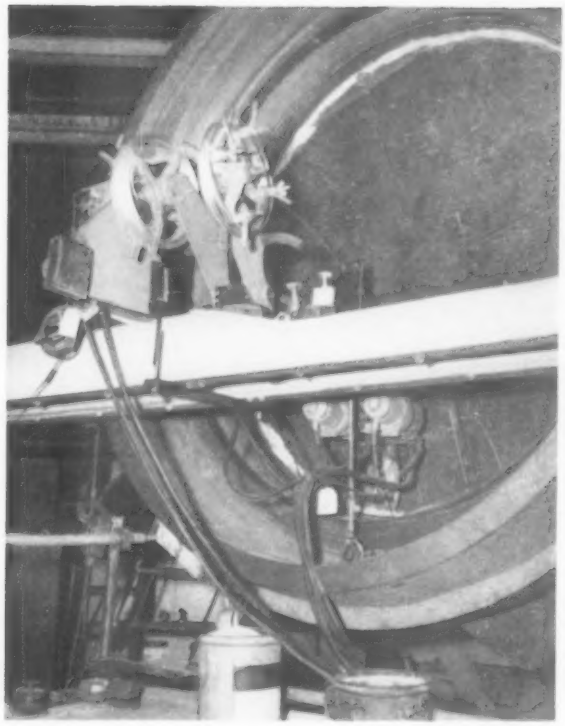

Fig. 4 Submerged-arc overlay weld for central-station blade ring

Series-arc deposit using Type 308 wires under bonded flux

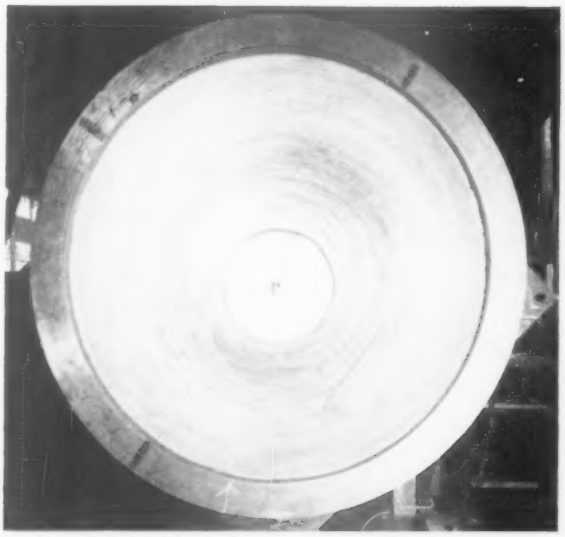

Fig. 5 Hemispherical carbon-steel head, approximately 53 in. ID, showing first-pass overlay deposited by series-arc technique using Type 308 and 312 wires and a bonded flux

Additional layers of Type 308 weld metal will be deposited on top of this layer to complete the cladding operation. Wall thickness ($3^1/_2$ in.) would make fabrication from roll-clad plate more expensive than method shown

Fig. 6 Single-layer overlap containing 20% chromium, obtained with mild-steel filler wire under a chromium-reinforced bonded flux

Base plate is carbon steel. X1

paired 309 and 308 wires, or paired 312 and 308 wires would be used in a critical application (to resist dilution and to obtain the highest corrosion resistance in the second and third layers of the overlay weld), it was sufficient in this case to weld the entire clad area with 308 wires. Face- and side-bend tests, both transverse and longitudinal to the direction of welding, all proved satisfactory.

Overlay welding combined with the series-arc technique is an attractive procedure when a corrosion-resistant surface is needed on a specially shaped object, such as a cone or a dished head. A typical illustration is shown in Fig. 5. The economy of this method will depend largely on the plate thickness, the thickness of the stainless layer and the availability of clad plate in the thicknesses of plate and cladding needed. If the weldment is intricate, clad steel, even when available, may prove more expensive to fabricate than is a steel base overlayed with stainless steel by welding. For pressure vessels whose wall thickness exceeds $3^1/_2$ in., cladding the fabricated vessel entirely by overlay welding, using the series-arc bonded-flux method, is expected to cost less than making the vessel from rolled-clad plate. The break-even point is certainly lower than $4^1/_2$ in.

Stainless filler wire need not always be used for such overlays. The extent to which alloying elements can be deposited on a steel plate, using mild-steel wire under an alloy-reinforced bonded flux, is illustrated in Fig. 6. This cross section shows a 20% chromium weld deposit, obtained in a single-layer overlay of overlapping beads (by a single arc), the chromium coming entirely from ferrochromium additions to the submerging flux. This same technique can be used to produce hard-surfacing overlays, and those combining hardness with corrosion resistance.

Naturally, the addition to a weld of major quantities of metallic alloys requires close control of the welding procedure, as the latter in turn controls the weld-metal chemistry. By strictly adhering to a scheduled procedure for the current, polarity, voltage, speed of travel, wire extension length and straightness, inclination of the wire, bead overlap or spacing, height

of flux burden and preheat or interbead temperature, the desired weld analysis can be consistently reproduced.

Narrow-Groove Welding

Still under investigation is another functional feature of the new fluxes, with potential savings in the cost of deep groove welds. These fluxes have an improved "wetting" action, which promotes wall washing in heavy butt welds, and greatly decreases undercutting and slag entrapment. The beads have a smooth concave surface which also facilitates slag removal. The cost saving will result from the use of a much narrower joint design than customary. The welding wire will be fed into the groove in a constant vertical position. The unique wetting action of the flux will cause the advancing weld metal to wash, or climb, both walls in a single pass. Figure 7 shows an experimental butt weld in plates $2^1/_2$ in. thick. Because of the danger of slag entrapment and removal difficulties with conventional fluxes, a wide joint using many split passes is now normally used, so that the welding wire can be shifted toward the sides of the groove for split-pass welding, and so that heavy slag-removing and bead-chipping equipment can be manipulated down in the groove. The proposed narrow joint design would require about one-third less welding time and filler metal, and should lead to fewer rewelds caused by trapped slag or other common defects. The danger of bead cracks, because of the concave contour of the weld, will depend on the bead thickness which is deposited, but we believe adequate control can be obtained through adjustment of the travel speed and current settings along with the right wire size.

Summary

To summarize the highlights of the bonded-flux story, a new type of flux has been developed which is produced by a unique method requiring much lower maturing temperatures than have heretofore been possible. This has permitted controlled variation of weld chemistry through incorporation in the flux of alloying elements, deoxidizers, strong fluxing agents... duplicating for submerged-arc welding the whole range of formulation used by the covered-electrode manufacturer. Even the identifying color has been added to distinguish the fluxes for stainless steel from those for low-alloy steel, and both of these from the special fluxes with specified alloy enrichment. The color will also reveal any contamination from other fluxes (as when a hopper is not cleaned out).

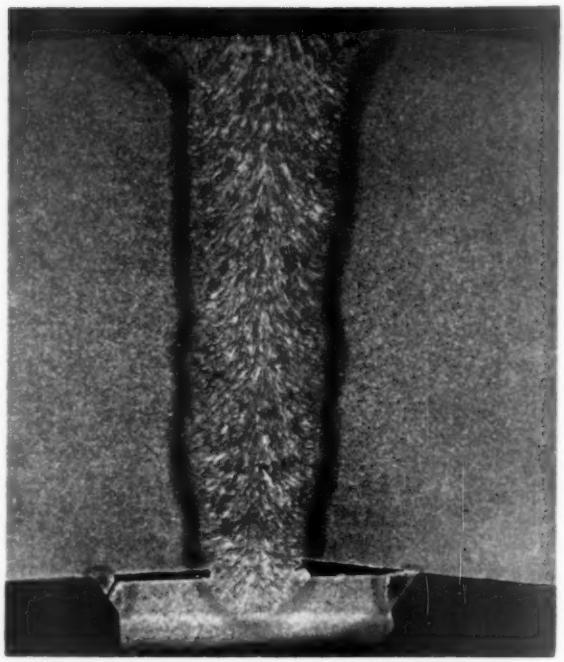

Fig. 7 Cross section of narrow-groove butt weld in $2^1/_2$-in. thick 2Cr–1Mo plate, welded with bonded flux and 2Cr–1Mo filler wire

Root spacing $^1/_4$ in.; plates were inclined 10 deg to provide the desired groove angle. Single weld passes washed both walls of groove because of wetting action of bonded flux. No split passes were used. X $1^1/_4$

A period of vigorous growth and expanding application is predicted for the old art of submerged-arc welding, stimulated and now made possible by the versatile properties of the bonded type of flux.

Acknowledgment

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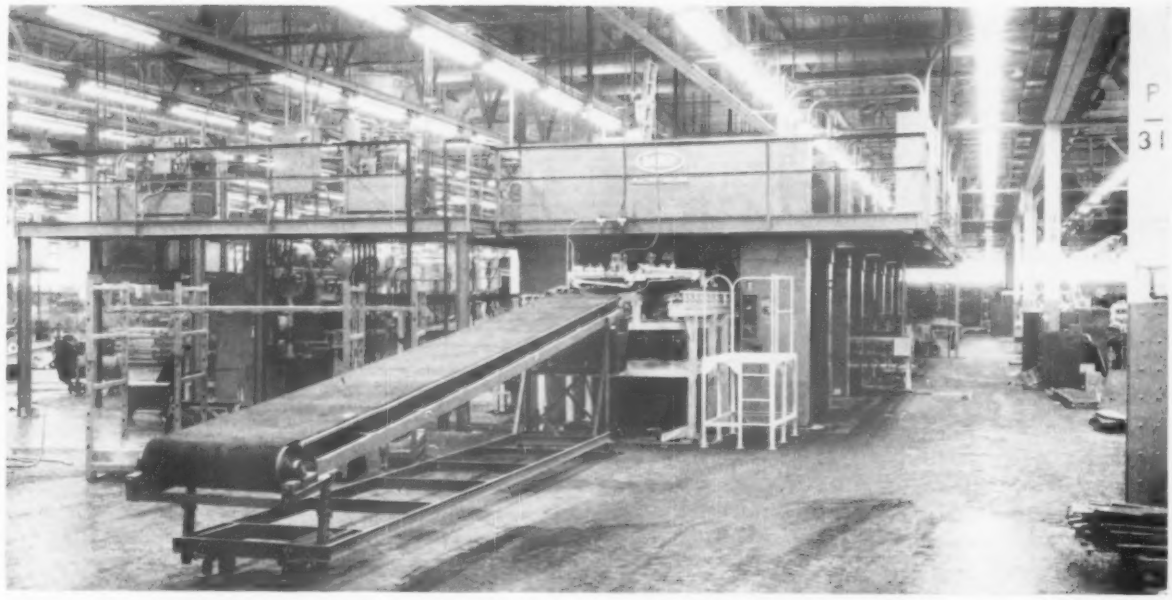

Rear floor pan line at the Ohio Stamping Plant of Chrysler Corp., showing busway, welding and automation

A NEW WELDER BUSWAY DISTRIBUTION SYSTEM

Paper covers an engineering study made during the preliminary stages and final design of the electric distribution system for a large stamping plant

BY LAWRENCE E. FISHER AND ROBERT W. DAILEY

General Description of Plant, Load and Power Distribution System

The Ohio Stamping Plant of Chrysler Corp. at Twinsburg, Ohio, covers an area of 1,500,000 sq ft, approximately 34 acres. Power is supplied by the Ohio Edison Co. to supply the great number of motor loads and so forth for the heavy presses and other manufacturing equipment in the plant. The estimated short-circuit duty is 2,500,000 kva, based on long-range future plans. The estimated initial short-circuit duty is 600,000 kva three-phase symmetrical.

Power at 138-kv is supplied to three transformers rated 10,000/12,500 kva, 3 phase, 60 cycles, 138 kv–13.8 kv, connected delta-wye with secondary grounded. All of the resistance welding discussed in this report is supplied from one of the 10,000/12,500-kva transformers provided with a voltage regulator. The other transformers supply the press motors and other loads in the stamping plant.

L. E. Fisher is Manager associated with the General Electric Co., Plainville, Conn. and **R. W. Dailey** is associated with the Chrysler Corp., Twinsburg, Ohio.

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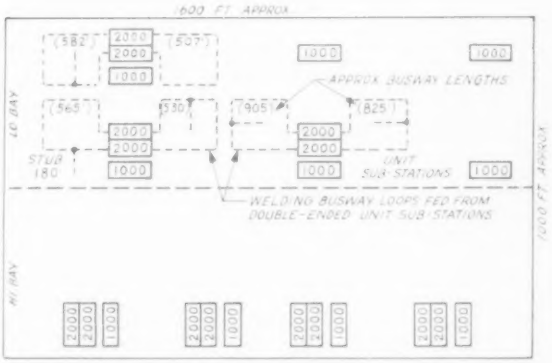

Fig. 1 Physical location of unit substations and welder busways at Ohio Stamping Plant

The 13.8-kv power is supplied to the metalclad switchgear through a 1200-amp breaker. Feeder breakers are also rated 1200 amp.

From the feeder breakers in the metalclad switchgear, power is supplied through runs of 3-conductor 350 MCM cable to 14–2000-kva transformers in seven

double-ended unit substations as shown in Fig. 1. The transformers are rated 2000 kva, 3 phase, 60 cycles, 13.8 kv–480 v, ungrounded secondary, connected delta-wye. Also there are 10–1000-kva transformers, supplying other than welding loads.

The entire plant area is covered with networks of approximately 13 miles of different types of busways. Light duty 50-amp, plug-in busways serve the fluorescent lighting load. Plug-in busways in ratings of 400 and 600 amp, having aluminum bus bars, braced for a 50,000-amp short-circuit current, serve the motor loads and general factory requirements. New 1600-amp (type LVDP) low voltage drop plug-in busways supply the heavy welding loads.

Three double ended unit substations, each with two 2000-kva transformers and with 3000-amp main and tie circuit breakers, supply the heavy welding departments. Each transformer feeds two runs of the 1600-amp type LVDP busway each protected by 1600-amp feeder circuit breakers. The runs are approximately 400 ft long, with the outer end of each run connected to the end of another run to form an 800-ft loop between two of the 2000-kva transformers. Actually the busway loops vary from 507 to 905 ft in total length. There are six welder busway loops. Thus the transformers are effectively tied in parallel on the 480-v side by two parallel runs of 1600-amp busway.

This paper deals primarily with these three double-ended unit substations and the 12 runs (or 6 loops) of 1600-amp busways feeding the heavy welding departments. These are shown in Figs. 1 and 2.

Method of Selecting System Elements to Feed the Resistance Welder Loads

A great amount of preliminary work was done in selecting the elements of the distribution system to feed the welder loads in this plant. As is customary on many jobs of this magnitude, the preliminary design was based primarily on previous experience and knowhow.

After making the preliminary selection of the system elements on the basis of this previous experience, it is then customary to make careful calculations covering all phases of the problem. This is done in order to make final selection of system elements that will be adequate not only to satisfy the thermal requirements, voltage-drop requirements, short-circuit requirements, but also to select protective devices that will coordinate properly, providing as much selectivity as possible and providing high speed tripping for both the maximum possible values of short-circuit current and also for the lower values of arcing fault current.

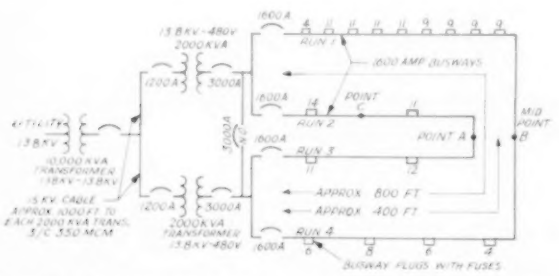

Fig. 2 One-line diagram of part of welder distribution system showing busways fed from one of the unit substations

This part of the paper is intended to show by an example how to select elements of the distribution system to feed welder loads, satisfying all these requirements.

Starting with the magnitude, location and characteristics of the welder loads, the selection of the elements of the distribution system proceeds as follows, assuming no previous field experience to aid in the selection.

The welding load consists primarily of approximately 500–65-kva single-phase welding transformers totaling about 36,000-kva nameplate rating.

The multi-transformer welding presses are similar to the type shown in Fig. 13, page 22 of the AIEE publication S-45 entitled "Power Supply for Resistance Welding Machines." The characteristics of the load are about as described on pages 22 and 23. The power factor is relatively high, about 70%.

In order to define the "during-weld" demand it was necessary to consider the probability of several welder groups firing at the same time. Two different methods of firing the welders were considered, but after a preliminary study it was decided to fire a group of welding transformers simultaneously 3-phase with $^1/_3$ of them connected to each phase of the 3-phase system. This eliminates the problem of dealing with single-phase currents drawn from a 3-phase system.

A preliminary study was made for the welding control to fire the welders single-phase by first firing a group of 4 welding transformers on phase AB for 15 cycles, for example, then 4 on phase BC for the next 15 cycles, then 4 on CA, etc. This method has an advantage, in that a smaller electrical distribution system can be used, but the unbalance of the 3-phase system was considered undesirable.

To provide as much flexibility as possible, a type of welding control was selected that can be used to fire the welders either single-phase or 3-phase. For this example, however, the welders will be fired 3-phase.

A close study of different methods of welding indicates that the design of the system depends more on the maximum number of welders fired simultaneously than on the average number. This is due to the fact that even with a fairly large number of welders, the number of welders which will be firing simultaneously based upon a given probability is relatively small. With this small number of over-lapping welders, it is very probable that the welders that are welding simultaneously during the same 15-cycle interval may all be the ones having the maximum number of welding transformers. Thus, regardless of the method used, it would be desirable to make an effort to reduce the maximum number to be fired simultaneously, especially if there are only a few groups containing the maximum number.

For example, the following is a list of the number of transformers fired simultaneously in the different stages of welding the front and rear floor pans. Since no more

than 14 are fired together, except in the 2nd, 3rd, 4th and 5th stages, it is suggested that these stages be split in two, firing half the transformers in one 13-cycle period and the other half in the following 15-cycle period. This reduces the maximum number from 22 to 14 and the average in the front floor pan (which is the heaviest loaded welding operation in the plant) from 12 transformers per firing to 8.3.

Welding Transformer Lineup—Ohio Stamping Plant

	Operation	*Number of transformers*	
Front floor pan	1st Stage	4	
	2nd Stage	22	
	3rd Stage	22	
	4th Stage	18	
	5th Stage	18	
	1st Stage table top	4	
	2nd Stage table top	6	
	3rd Stage table top	8	
	4th Stage	6	108
Rear floor pan	1st Stage	14	
	2nd Stage	11	
	3rd Stage	12	
	4th Stage	11	48
			156

The heavy welding departments are supplied by three double-ended unit substations, each having two 2000-kva transformers with a main circuit breaker for each transformer, a tie circuit breaker and feeder circuit breakers. Each unit substation is centrally located with respect to a number of the multitransformer presses (Fig. 2).

The 65-kva welding transformer loads are in groups of a maximum of 14 (5 per phase) fed from each fused switch busway plug. The maximum of 14 transformers are fired simultaneously by ignitrons. Thus, the total number of groups in run 1 is 9, in runs 2 and 3 is 2, and in run 4 is 4.

Test indicates that the during-weld current of each 65-kva welding transformer is 250 amp. All welders will weld for 15 cycles out of each 9 sec; thus, the duty cycle is 0.0277.

In a consultation with the plant engineers it has been agreed that it is desired not to have more than one bad weld per 10,000 ($^1/_{100}$ of one percent). Thus, the system design should be based on a probability of one bad weld per 10,000.

It is decided, further, to standardize busway sizes using the front and rear floor pan department as a basis, since it is now the most heavily loaded. The standardization is desired because of the ever-changing conditions in the automotive industry. The number of welding transformers fired simultaneously at any location can be changed easily. With two busway runs 400 ft long from each of the two transformers in each unit substation as shown in Fig. 2, if the ends of the busways at the extreme right are connected together, as shown, the transformers will then be connected in parallel by the two parallel 800-ft loops of busways. Such an arrangement has several advantages.

1. With a single large load connected near the input end of either busway, the two transformers will divide the current in the ratio of approximately 60% and 40%. Thus with almost any practical loading around the loops, the transformers will divide the load almost equally.

2. As a result of this sharing of the load, the voltage drop in the transformers will be reduced greatly.

3. Any single large load (or center of several distributed loads) located near the mid-point of one loop, such as at point A or B in Fig. 2, will result in about equal currents flowing in the two halves of the loop. Any load at point C, at the mid-point of one run ($^1/_4$ of the loop) will result in a division of current of 65% and 35% in the two parallel paths around the loop.

For Each Part of the System, It Is Necessary to Make Two Separate Calculations

1. *Thermal Requirement.* First, a calculation is made to determine the ampere rating of the fuse, busway or other element to satisfy the thermal requirement. This is sometimes called the equivalent continuous current. For each group of welders, use the formula:

$$I = I_d\sqrt{\text{duty cycle}}$$

in which: I is the ampere rating required, I_d is the total "during-weld" current of all the welders fired simultaneously. Select a fuse or molded-case circuit breaker about 25% larger than the ampere rating (I) calculated in order to prevent nuisance blowing or tripping. This safety factor is not necessary for a busway, cable, transformer or magnetic circuit breaker.

To determine the total equivalent continuous current[3] to a number of welders connected to one busway use the following formula in which I_T is the total equivalent current, d is the duty cycle and I_1, I_2. . .etc., are the during-weld currents in the different welders or groups of welders.

$$I_T = \sqrt{(d - d^2)\,(I_1^2 + I_2^2 + \ldots.) + d^2\,(I_1 + I_2 + \ldots)^2}$$

2. *Voltage-Drop Requirement or Total During-Weld Requirement.* Second, a calculation is made to determine the total maximum "during-weld" current. This takes into consideration the probability of several welders firing simultaneously.

Taking each fuse, circuit breaker, busway or other element one at a time, (unless conditions are identical) preferably starting at the smallest branch units, such as the fuses in the busway plugs, determine the total number of welding transformers fed through that fuse; then using the proper probability[4] curve from Fig. 3, determine the number of simultaneous welds. Use the bottom scale. (Obviously, the curves in Fig. 3 would not be required if all welders are fired simultaneously by ignitrons. In such case take the total number of welders.) In either case multiply this number by the "during-weld" current of one welding transformer to determine the maximum total "during-weld" current I_T passing through the fuse (or other element). Use

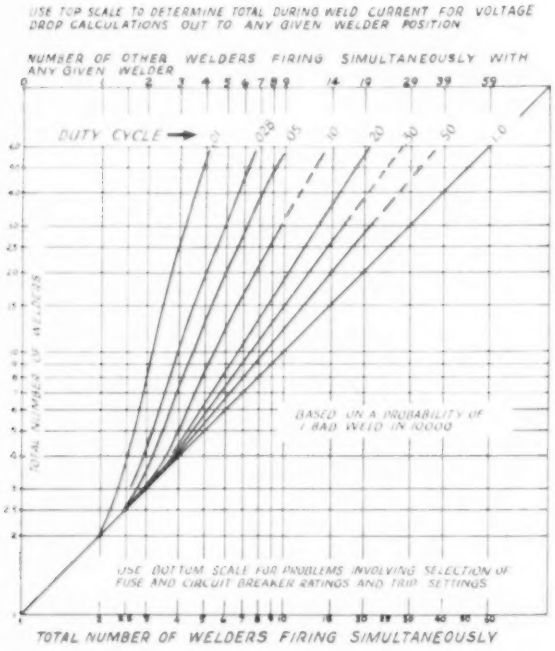
USE TOP SCALE TO DETERMINE TOTAL DURING WELD CURRENT FOR VOLTAGE DROP CALCULATIONS OUT TO ANY GIVEN WELDER POSITION
NUMBER OF OTHER WELDERS FIRING SIMULTANEOUSLY WITH ANY GIVEN WELDER
DUTY CYCLE
BASED ON A PROBABILITY OF 1 BAD WELD IN 10000
USE BOTTOM SCALE FOR PROBLEMS INVOLVING SELECTION OF FUSE AND CIRCUIT BREAKER RATINGS AND TRIP SETTINGS
TOTAL NUMBER OF WELDERS FIRING SIMULTANEOUSLY

Fig. 3 Probability curves for determining number of welders firing simultaneously

maximum values of "during-weld" current, whereas for the thermal requirement an average value may be used. Then for the fuse or circuit breaker previously selected to satisfy the thermal requirements, check its time-current curve to make sure that it will not blow (or trip) for this total "during-weld" current I_T in the time that the "during-weld" current flows. Increase the ampere rating of the fuse or circuit breaker if necessary. Note that in the example to follow, a safety factor is applied to prevent nuisance tripping. Tripping of circuit breakers, even though it occurs only once or twice a week, is very undesirable.

For the busways, cables or transformers previously selected to satisfy the thermal requirements, calculate the voltage drop for this total "during-weld" current I_T.

I_T is calculated using the probability curves, the same as for fuses or circuit breakers. It is necessary, however, to subtract one from the total number of connected welders before using the curves because the voltage drop or variation at any welder is due only to variation in current flowing to other welders. Use the upper scale in Fig. 3. There is no variation due to the current flowing to the welder under consideration because every time it fires, it draws the same current. Obtain from the curve the number of welders firing simultaneously. Then multiply by the during-weld current of one welder (or group) to determine the total during-weld current for the voltage-drop calculation.

If the voltage drop is too high, a larger busway or transformer would then be selected. In general, the voltage drop should not exceed 15%, although in critical work a lower limit is required.

In the curves of Fig. 3, note that half any given number of welders results in more than half the corresponding number of simultaneous welds. Thus, if a main feeder has two equal branches, the number of simultaneous welds for the branches is more than half that for the feeder.

With this preliminary information it is now required to determine the sizes of the fuses in the busway plugs, the size of the busways and *protective* feeder circuit breakers, and the size of the main circuit breakers and transformers.

Solution of Problem: Thermal Requirement

First starting at the smaller branch elements out near the load make a selection of the busway plugs and fuse sizes, followed by the busways, feeder breakers, main breaker and, finally, the transformer.

Fuses in Busway Plugs

For each group of 3–65-kva transformers (one per phase) the single-phase during-weld current is 250-amp or 433-amp 3-phase = I_d. The current based on the thermal requirement $I = I_d\sqrt{\text{duty cycle}} = 433 \times 0.166 = 72$ amp. Recommended fuse sizes are shown in Table I. This assumes 433 amp as the average current.

Busway Number 1 with No Tie Busway at End

The ampere rating required for the busway is 72 amp for each group of three transformers. The total of 84 transformers or 9 groups would require a busway rating of 790 amp calculated by the method developed in reference 3 (Fig. 2).

Busway Number 4 with No Tie Busway at End

Seventy-two amp for each group of three transformers amounts to approximately 342 amp for the 24 transformers connected to Busway 4 using the same method.

Busways 1 and 4 Forming a Loop (connected at point B)

Although an 800-amp busway could be used for Busway 1 and a 400 amp for Busway 4, it was previously decided to standardize the busway sizes and use the double loop system. By preliminary voltage-drop calculations (conducted later) similar to those described under the heading "Voltage Drop of Busway Loop 1–4," it was determined that the busway ratings must be 1600 amp.

Feeder Circuit Breakers

The current rating of the feeder circuit breakers should generally be about the same size as the busways. The 1600-amp circuit breaker was selected as a standard for all 12 feeder circuit-breaker applications.

Main Circuit Breakers and Transformers

The total equivalent continuous current calculated for all the welder loads shown in Fig. 2 is 1180 amp. Because of the double parallel loops, a 600-amp rating for each transformer should be satisfactory to satisfy the thermal requirement. Later, however, it will be found that 2000-kva transformers are required because of voltage drop. A 3000-amp main circuit breaker was actually selected as a standard.

Table 1—Recommended Fuse Sizes

Number of welding transformers connected to one busway plug	*During weld current I_d, amp*	*Equivalent continuous current I, amp*	*Recommended fuse sizes*
3	433	72	100
6	866	144	200
9	1300	216	300
12	1732	288	400
15	2166	360	450

Demand and Diversity Factors

In this example, no demand factor and diversity factor have been used, other than those provided for in the method of determining the equivalent continuous load for the groups of welders. As processes become automated to a greater degree, it becomes increasingly dangerous to use arbitrary demand factors. If it is known that additional welders have been installed in order to keep the production line moving at its normal rate with some equipment down for repairs, then an appropriate demand factor can be applied. Also if it is known that the average during-weld current of all the welders connected to one busway, for example, is less than that for the smaller group of welders connected to one busway plug, then an appropriate diversity factor can be used.

Summary

This now establishes a thermal rating for all elements of the system. It is important, however, not to forget to make the second calculation to consider the voltage drop requirement or total during-weld requirement of all elements. These calculations will require some of the system elements to be increased in ampere rating.

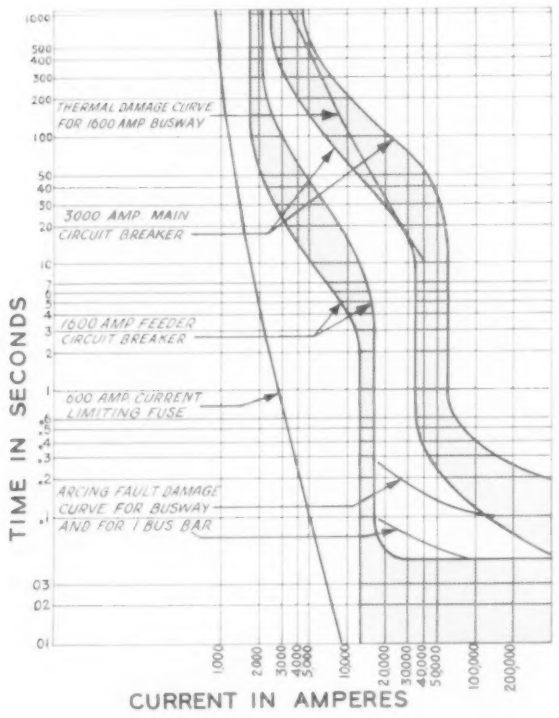
THERMAL DAMAGE CURVE FOR 1600 AMP BUSWAY
3000 AMP. MAIN CIRCUIT BREAKER
1600 AMP FEEDER CIRCUIT BREAKER
600 AMP CURRENT LIMITING FUSE
ARCING FAULT DAMAGE CURVE FOR BUSWAY AND FOR 1 BUS BAR
TIME IN SECONDS
CURRENT IN AMPERES

Fig. 4 Time-current curves for protective devices and damage curves for the 1600-amp busway

Solution of Problem: Voltage Drop or Total During-Weld Requirement

Fuses in Busway Plugs

For each group of welding transformers, shown in Fig. 2, the ampere ratings of the fuses previously selected to satisfy the thermal requirements, should be rechecked as follows: From the time-current curves of the fuses, determine the time required for the fuse to blow for the during-weld current indicated in Table 1. It is important to make this check, to make sure that the fuse will not blow for this magnitude of during-weld current in the 15 cycles that the during-weld current flows. To allow a little safety factor, it would be well to increase the size of the fuse, if in any case, the fuse at this magnitude of current blows in less than, say, 30 cycles.

As an example of this calculation, for the 200-amp fuse previously calculated to satisfy the thermal requirement for six welding transformers, the blowing time of the fuse for the during-weld current of 866 amp is about $7\frac{1}{2}$ sec. Obviously, there would be no danger of the fuse blowing at this magnitude of current in the during-weld time, which is only 15 cycles. Note that the probability curves are not used in this calculation because all welding transformers in any one of these groups are fired simultaneously. Since this 200-amp fuse satisfies both the thermal requirements and the total during-weld current, it can now be recommended as the proper fuse to use to protect this group of six welding transformers.

Feeder Circuit Breakers

For the feeder circuit breaker protecting the busway loop 1–4 which has 13 groups of welders, it is determined from Fig. 3 that the total number of welders firing simultaneously (bottom scale) for a duty cycle of 0.0277 is 4.3. Before entering the curves in Fig. 3, the number of welders (13) may be reduced by the demand factor, if one has been established. It is dangerous to use a diversity factor in determining the total during-weld current to such a small number (4.3) of welders unless the probability of the average during-weld current for these 4.3 welders exceeding the average for the total group of 13 is checked and found to be less than the probability used in Fig. 3.

4.3 x 1732 = 7450 amp. With the known locations of the large welding presses around the loop, not more than 65% of this total current (about 4900 amp) will pass through one feeder breaker. The total of 7450 amp, however, would require almost 10 sec to trip the 1600-amp feeder circuit breakers. Certainly, there would be no danger of them tripping in 15 cycles.

Main Circuit Breakers

For the total of 17 welding groups connected to both

Table 2—Percent Voltage-Drop Values on 480-Volt Base

	3-Phase			1-Phase		
	0.3 PF	0.5 PF	0.7 PF	0.3 PF	0.5 PF	0.7 PF
System component	*Percent Voltage Drop Per Ampere*					
10,000-kva transformer	0.00065	0.00060	0.00051	0.00075	0.00068	0.00059
2000-kva transformer	0.00227	0.00218	0.00185	0.00262	0.00246	0.00214
	Percent Voltage Drop Per Ampere Per 100 Feet					
350-MCM cable	0.0000015	0.0000017	0.0000019	0.0000017	0.0000019	0.000020
LVDP5 busway	0.00024	0.00029	0.00032	0.00026	0.00031	0.00035
	Percent Voltage Drop Per Ampere					
Combined 1000 ft of 350-MCM cable and 2000-kva transformer	0.002285	0.002147	0.001869	0.002637	0.002479	0.002160

loops of busways, each having a duty cycle of 0.0277, the total number of welders firing simultaneously from Fig. 3 is 4.7 (use bottom scale.)

Assuming that these groups have 12 transformers each, the total during-weld current would be 4.7 x 1732 amp or 8150 amp. Of this total current, only about $^1/_2$ would pass through each feeder breaker. Examining the time-current curves of the breaker (Fig. 4), it is apparent that there would be no danger of the 2500- or 3000-amp main breakers tripping in 15 or 30 cycles for this value of slightly over 4000 amp. Thus, either the 2500- or 3000-amp circuit breakers could be used for the six places in this system where main breakers are required.

Voltage Drop of Busway Loop 1–4

Referring to probability curves in Fig. 3, the number of simultaneous welds to be used for voltage-drop calculations (upper scale) for a total of 13 welders in this loop (for the duty cycle of 0.0277) is 3.3. Since the maximum welder group containing about 12 welding transformers draws 1732 amp, the total maximum during-weld current is 3.3 x 1732 = 5720 amp.

Now assuming that these 3.3 welders which happen to be firing together are located out near the mid-point of the loop, there would be 2860 amp-flowing in each half of the loop.

From Table 2, the percent voltage drop of the 1600-amp type LVDP5 busway selected for this application is 0.00032% per ampere per 100 ft with the entire load at the end of the run. Thus the percent voltage drop in this busway is 0.00032 x 2860 x 4 = 3.66. This appears very satisfactory but, of course, the other elements of the system must be considered.

Voltage Drop in Transformer

For the total of 17 welding groups each with a duty cycle of 0.0277, the number of simultaneous welds from Fig. 3 (top scale) is 3.7. The total maximum during-weld current is (from Table 1) 2166 for the largest group (with 14 welders) + 2.7 x 1732 = 6846.

Of this total current, approximately half would come from each transformer. From Table 2 the voltage drop in the cable and 2000-kva transformer previously selected for this application is 0.00187% per ampere at 0.7 PF. Therefore, the voltage drop for 3423 amp is 6.40%.

Total Voltage Drop

Then the total voltage drop in the busways and unit substations is 6.4% in the 2000-kva transformer and cable +3.66% in the busway or 10%.

It now remains to consider the voltage drop in the 10,000-kva 138-kv to 13.8-kv transformer which feeds power to three of these double-ended unit substations.

If the load on the other two substations is assumed to be the same as on this one, there would be a total for 51 welding groups (Fig. 2) and from Fig. 3 there would be 6.2 simultaneous welds. 6.2 x 1732 = 10,800 amp. From Table 2 this transformer has a voltage drop of 0.00051% per amp or 5.5% for 10,800 amp.

Then the total voltage drop is 10 + 5.5 = 15.5%. This appears satisfactory, especially in view of the fact that the other two unit substations are not expected to be as heavily loaded as the one shown in Fig. 2. But changes were required in the ampere ratings of the system elements as selected to satisfy the thermal requirements originally, thus illustrating the importance of making voltage-drop calculations.

Selection of Protective Devices to Achieve Selectivity and Maximum Protection for Equipment and Personnel

Selectivity

One of the best ways to obtain selectivity between the feeder circuit breaker protecting the busways in these double parallel loops and the main circuit breakers

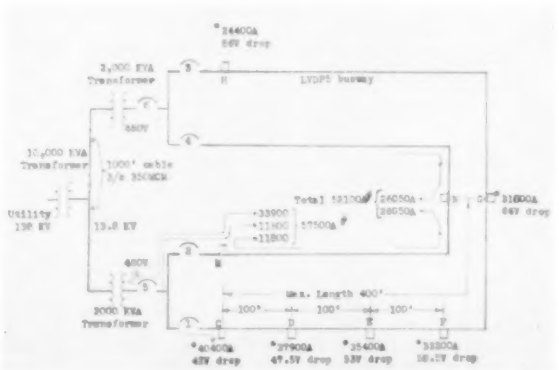

Fig. 5 Calculated values of short-circuit current and division of current in parallel paths

would be to use the selective system employing General Electric type AK-1 circuit breakers. In this system, the main breaker is equipped with a delay of a few cycles, just sufficient to allow the feeder breakers to trip without tripping the main breaker. It is believed that it is very important to keep this delay at an absolute minimum, because if an arcing fault should occur in the system between the main breaker and the feeder breaker, it is desirable for the main breaker to trip as quickly as possible.

In the specific sizes of breakers used in the double loop system, it appears that selectivity can be achieved by using standard circuit breakers with the usual inverse time delay for overloads in addition to the instantaneous trip device.

In the overload range, Fig. 4 shows that the 1600-amp feeder breakers will trip for all overloads without tripping the 3000-amp main breakers.

Now to consider the selectivity in the short-circuit region Fig. 5 indicates that, with both loops operating in parallel, the maximum possible short-circuit current is 57,500 amp (at busway plug M) near the input ends of any of the busways and about 52,000 at the farthermost point N, which is at the mid-point of one loop. This assumes a 800-ft loop. The short-circuit value at any intermediate point around the loop would be something between these two values. For the 57,500-amp short circuit at the input end the feeder breaker, with instantaneous trip device set at 10 times, will be tripped by its instantaneous trip device by the 45,700-amp current.

These short-circuit current values as calculated were based on the 1.25 factor. Actually the X/R ratio in this Twinsburg plant varies from 2.7 to 4.4. A more realistic average factor is 1.1 instead of 1.25 for a 3-phase short circuit. In case of a single-phase short circuit, the factor would ordinarily be higher. In these low-voltage systems, however, a single-phase short-circuit value is reduced to about 86% of the 3-phase value. Therefore, it appears that for circuit breaker-coordination studies the factor of 1.1 should be used for all calculations of maximum possible short-circuit currents, either 3-phase or single phase. Thus, the maximum short-circuit value at point M is 57,500 x 1.1/1.25 = 51,000 amp and for point N, 46,000 amp.

The 1600-amp feeder breaker would trip instantly (in 3 cycles) since from Fig. 5 the current passing through it is approximately (33900 + 11800) times the ratio 1.1/1.25 = 45700 x 0.88 = 40,000 amp.

The current passing through the main 3000 amp is 0.88 x 33900 = 30,000 amp. Thus, if its instantaneous trip device is set at 12 times or 36,000 amp it will not trip. Calculations indicate that none of the other breakers will trip. It appears then that satisfactory selectivity has been achieved providing a high degree of protection for the maximum possible values of short-circuit current. This is an interesting advantage of the double-loop system. In the radial system with a 3000-amp main breaker and 1600-amp feeder breakers selectivity cannot be achieved for values of

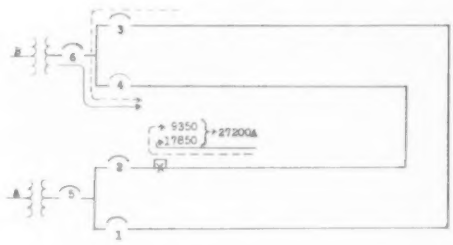

Fig. 6 Short-circuit currents after breaker No. 2 trips

short-circuit current higher than 36,000 amp (12 x 3000) because the instantaneous trip devices of both the feeder breaker and main breaker will be actuated in the first half cycle.

Arcing Faults

In case of an arcing fault, the current would be reduced by the arc resistance to a value estimated as approximately 70% of these values on a 480-v system, or about 40,000 amp for the fault near the input end and 36,000 amp at the farthermost point. These values are symmetrical values to take care of the minimum possible condition.

It is considered to be extremely important to trip the feeder breakers instantly, in case of an arcing fault, to reduce to a minimum the damage done by the arcing and the danger to personnel. Since the magnitude of arcing fault current for a fault at the mid-point of one run is only 36,000 and only about half this value or 18,000 amp would come from each direction, it then *appears* important to set the instantaneous trip device of the 1600-amp feeder breakers not higher than 10 times, so they will trip instantaneously for any current over 16,000 amp.

Another point that must be checked carefully is an arcing fault current near the input end of the busway at busway plug M, in Fig. 5. When the fault first occurs at this point with all breakers closed, the short-circuit arcing fault-current magnitude is about 40,000 amp symmetrical (0.70 x 57,500) with about 31,000 amp passing through the feeder breaker number 2. With this breaker set at 10 times, its instantaneous trip device will function. Then Fig. 6 shows the magnitude of current that would flow from the other direction through feeder breaker number 4. The maximum value is 27,200 amp but for an arcing fault this would be reduced to 70% or about 19,000 amp symmetrical. Fortunately this value will trip the breaker number 4 if its instantaneous trip device is set not higher than 10 times. Perhaps 8 times would be a safer setting.

High-speed tripping was given careful attention in the design, because it is known that considerable damage is done by arcing faults in industrial plants. It is the authors' opinion that the most important single action that can be taken to reduce this damage is to select with great care the instantaneous trip setting of all circuit breakers, to make sure that they will trip to interrupt the current quickly (in not more than 4

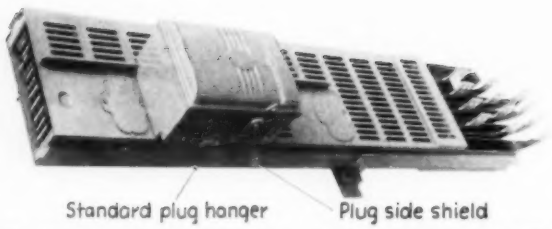

Fig. 7 New low-voltage-drop plug-in busway rated 1600 amp with busway plug attached

or 5 cycles) for an arcing fault occurring at any point in the system.

Figure 4 shows the time-current curves and also the instantaneous trip points of the 1600- and 3000-amp circuit breakers.

Superimposed on this curve is the thermal damage curve for the busway. This curve shows how long the busway can carry given amounts of current without exceeding its temperature limitation of 55° C rise. Also on this curve are shown the arcing damage curves for the more massive aluminum conductor at the joints where all bus bars of like polarity are connected together and also for individual bars.

Since the bus bars of the LVDP busway are taped, there is no danger of arcing except at the bare spots at the joints or at the plug-in openings. In this type of busway the busway plugs make contact with three bars of the multi-bar interlaced arrangement of bars. The fuses in the busway plugs protect the branch circuit, and the individual bus bars for a short circuit on the load side of the fuses. For an internal arcing fault on these individual bus bars, however, the fuse, not being in the circuit, cannot provide any protection. For this reason it is desirable to set the instantaneous trip device on the feeder circuit breaker low enough to protect the individual bars.

Referring to the curve showing the arcing fault damage for one bar of the busway, this curve shows about how long a given amount of current can be allowed to flow through an arcing fault burning on one bar in the busway without destroying more than 50% of the conductor material. Reading from the curve, the bus bar could stand 20,000 amp for about 5 cycles and 100,000 amp for about 3 cycles. The newer circuit breakers that trip in the range from 2 to 4 cycles appear to be fast enough provided the instantaneous trip device is set low enough.

Some engineers may question the advisability of attempting to protect from arcing faults, believing that regardless of what is done, replacement may be necessary anyway. It is the authors' opinion, however, that low voltage arcing faults are so destructive and dangerous that far greater care should be exercised in selecting protective devices so that the damage and danger will be reduced to a minimum.

Arcing Faults in Switchboards

In this study both the maximum possible values of short-circuit current and also the minimum arcing fault currents have been considered for short circuits at all points in the busways. No consideration has been given to a short circuit in the unit substation switchboard between the main breaker and the feeder breaker. A short circuit on the line side of one of the feeder circuit breakers, for example, would be approximately the same as at point M, Fig. 5, or 40,000 amp minimum for an arcing fault. Only about 24,000 amp minimum would pass through the main breaker whereas its instantaneous trip device is set at 36,000 amp. Under this condition the main breaker would trip after considerable delay but the instantaneous trip device would not function. Considerable damage would be done to the bus bars in the switchboard.

To provide high-speed protection for arcing faults in the switchboard without losing selectivity, it appears necessary to use induction disk relays to trip the main breakers after a delay of, say, 8 cycles. This would provide high-speed tripping and still the 8 cycles would be sufficient time to allow the feeder breaker to operate (in 3 cycles) to interrupt current to any short circuit on its load side without tripping the main breaker. Another equally-good arrangement would be the use of the short-time delay in the selective system.

Emergency Condition

In an emergency it is possible that the feeder breakers 1 and 4 may be closed leaving the feeder breakers 2 and 3 open (Fig. 5). The entire length of 800 ft of busway would be fed from one transformer. Under this condition the short-circuit current at point H, the extreme end of one run, would be 24,400 amp maximum with only about 17,000 amp in case of an arcing fault at the end. With the instantaneous trip device of circuit breaker 1, set at 10 times, it should trip to give protection for this arcing fault. This is a borderline case, however, and there is a chance that the breaker might not trip on the instantaneous trip device. A setting of 8 times might be required.

Another possible solution would be to place a disconnect switch at the midpoint of both loops. Then the maximum length of busway would be only 400 ft, and the short-circuit current would be a little higher so the feeder breaker should trip satisfactorily even for an arcing fault.

Coordination with Fuses

In selecting the point at which the instantaneous trip devices are to trip, it is important, of course, to consider how they coordinate with the fuses in the busway plugs. On a system having this much short-circuit available only current-limiting fuses in the busway plugs should be used for two reasons. First, the fuses must have adequate interrupting ability. Second, it is highly desirable for these fuses to have a low value of I^2T to provide greater safety for arcing fault currents and provide a reduction in the forces on the smaller circuits which they protect.

Most current-limiting fuses blow so quickly on short circuit that there would be no danger of tripping the feeder circuit breakers before they blow, but it is im-

portant to check actually the curves to make sure that complete selectivity is achieved.

New Plug-in Type Low-Voltage Drop Busway

For the double parallel loops of busways feeding power to the heavy welding presses a new type of plug-in busway was selected. This busway employs the interlaced arrangement of bus bars. Figure 7 shows a fused busway plug mounted on one of the 10 openings available in a 10-ft length of the new busway known as type LVDP. These busways are available in a range of ratings from 600 to 4000 amp with either copper or aluminum bus bars. Any 10-ft length of this LVDP busway is interchangeable with a 10-ft length of standard LVD feeder busway.

Type LVDP busway rated 1600 amp with aluminum bus bars was selected for this Chrysler distribution system to feed the heavy welder loads.

This busway with 4 bus bars in parallel per pole is capable of withstanding the forces of a 100,000-amp short circuit. The 4 bus bars in parallel of each pole are connected together at every joint between 10-ft sections. The 100,000-amp short-circuit current divides among the 4 bus bars with about 25,000 amp per bar. This, together with the fact that the bus bars are effectively supported on insulators 12 in. apart, explains its high short-circuit strength.

In the spans between insulator supports of any busway, the forces during short circuit cause the bars to swing back and forth. In order to reduce the effect of this movement of the bus bars on the plug-in stabs of the busway plugs, the ten plug-in openings in each section of busway are positioned directly adjacent to the bus bar supports. Also the stabs and stab insulators are designed with sufficient flexibility to permit some movement. Based on tests on other similar devices, no damage is expected in either the busway or busway plugs for a 100,000-amp short circuit on the load side of current-limiting fuses mounted in the busway plugs.

Among the most important features of these plug-in busways are extremely low values of resistance, reactance and voltage drop. The voltage drop value is roughly half that of the conventional plug-in busways.

Assuming a current of 1600 amp at a power factor of 0.70 on the 1600-amp plug-in busway selected for this welder distribution system, the voltage drop is only 1.22 v per 100 ft with loads distributed along the run. With the entire 1600-amp load at the end, the voltage drop is 2.44 v per 100 ft.

Use of Series Capacitors to Improve the Voltage Regulation

It is known that series capacitors can be used to improve voltage regulation on systems with welder loads. The a-c network analysis test Case No. 15 proved that a remarkable reduction in voltage drop could be achieved on the Chrysler system by using series capacitors.

The graph in Fig. 8 shows calculated values of voltage drops or levels, first with and then without the use of series capacitors to nullify the voltage drop in the transformers.

After some preliminary trials it was determined that all the series capacitors can be grouped together near the 10,000-kva main transformer. It is important, however, to break the total bank into units, one for the 10,000-kva transformer placed in series with it, and one for each 2000-kva transformer, being careful to place each one in the individual branch circuit in series with one 2000-kva transformer.

The reason is that the series capacitor is unusual in that it can exactly nullify the voltage drop in a transformer or busway, and the voltage drop will be nullified for all values of load current from zero to maximum, *provided* that all the current which passes through the transformer or busway also passes through the capacitor and vice versa. Thus if only one capacitor bank were used and placed on the load side of the 10,000-kva transformer it could be adjusted to nullify the voltage drop in all transformers if all are fully loaded. But it is obvious that any decrease of current in any one or more of the branch transformers would cause a voltage drop in all the *other* branches in which the current had not changed. This is because the drop in current passing through the capacitor would make a reduction in the voltage rise in the part of the capacitor which was being used to nullify the drop in the *other* branches.

Possibility of Leading Power Factor

Actually only a small amount of capacitor kva is required to nullify the voltage drop in transformers or busways, since the voltage drop in these devices is only 5 or 10% of the total voltage. Thus it would

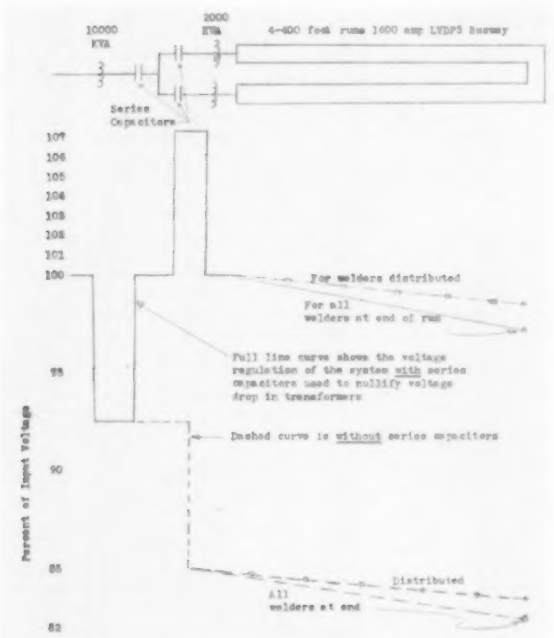

Fig. 8 Voltage levels on Chrysler welder system with and without series capacitors

Table 3—Electrical Parameters

System component	*Ohms*	*Percent ohms 666-kva base*	*Per unit ohms 20,000-kva base*
Utility 138-kv (2,500,000-kva S.C.)	1.42 +j 7.4	0.005 +j 0.026	0.0015 +j 0.0078
Transformer 10,000 kva	0.104 +j 1.52	0.036 +j 0.53	0.0108 +j 0.159
Cable 1000 ft	0.040 +j 0.032	0.014 +j 0.011	0.0042 +j 0.0033
Transformer 2000 kva	0.00126 +j 0.0062	0.28 + j 1.80	0.084 +j 0.54
Busway LVDP5			
Per 100 ft	0.00081 +j 0.00044	0.233 +j 0.1275	0.070 +j 0.0383
Per 400 ft	0.00324 +j 0.00176	0.933 +j 0.51	0.28 +j 0.153

appear that there would be no possibility of having a leading power factor. Theoretically, there is some possibility, however, because when the system is very lightly loaded to say, only 5 or 10% with high PF load, it would then be possible to have a leading power factor if the capacitor selected is larger than necessary to nullify the inductive kva in the transformers or busways. This is of little importance, however.

Series Capacitors for Busways

If all the load is connected at the end of the feeder, a capacitor can be selected so that the voltage at the end remains unchanged for all values of load from no load to full load. It is evident that the voltage level varies along the length of the run. Therefore, for busways such as plug-in busways where the loads are distributed along the length of the run, it is not possible to select series capacitors that will completely nullify the voltage drop to all points along the busway. Thus there appears little advantage in using a series capacitor for plug-in busways. One can be used to hold the voltage level constant at about the $^1/_3$ point in the run, but there will be a voltage rise at the input end and a drop at the output end equal to about half the normal drop.

The Chrysler system was designed to provide satisfactory voltage regulation without using capacitors with the intention of considering their use at a later date when production increases beyond a certain level.

A-C Network Analyzer Tests

The electric distribution system feeding the welder load at the Ohio Stamping Plant of Chrysler Corp. was simulated by a 3-phase test on the a-c network analyzer at the General Electric Co. in Schenectady.

Parameters of the 10,000-kva 138-kv transformer, the 13.8-kv cables, the 2000-kva 13.8-kv transformers, and the double loops of LVDP busways as tabulated in Table 3 were set up on the analyzer.

Sixteen tests or case studies were conducted using the network analyzer:

Case 1. Fault at point A at center of 800-ft loop of LVDP5. Base kva = 20,000 unit current = 24,060 amp = 100%. All tests with 400-ft runs of LVDP5 busway (800-ft loops unless noted otherwise.) On all tests the base voltage is 480 v line to line or 277 v line to neutral.

Case 2. Fault at secondary side of one 2000-kva transformer. Base kva = 20,000 unit current = 24,060 amp = 100%.

Case 3. Apply 1–4000 A 3ϕ load at point A. 0.30 PF. Base kva = 3000 unit current = 3610 amp = 100%. These values remain the same for all remaining tests.

Case 4. Apply 1–4000 A 3ϕ load at point A and one at point B 0.30 PF.

Case 5. Apply 1 – 4000 A 1ϕ load at point B 0.30 PF.

Case 6. Apply 1 – 4000 A 3ϕ load at point A and 1ϕ at Point B 0.30 PF.

Case 7. Apply 1 – 8000 A 1ϕ load at point B 0.30 PF.

Table 4—Voltage Drop Values from A-C Network Analyzer Test

	% Voltage drop in				*Total % voltage drop at load*		*Load at Point A**	*Load at point B**
	10,000-kva transformer	*Cable & 2000-kva transformer*	*Busway to point A*	*Busway to point B*	*Point A*	*Point B*		
3	2.1	3.9	2.0	...	8.0	...	3651	...
4	4.2	7.5	1.8	1.8	13.5	13.5	3426	3423
5	not recorded	6.8	...	2.7	...	9.5	...	3602
6	4.2	8.0	2.6	2.7	14.5	14.9	3523	3390
7	5.4	7.5	...	4.6	...	17.5	...	6600
8	4.8	8.1	...	4.5	...	17.0	...	6570
9	4.2	6.3	...	5.8	...	16.3	...	6570
10	6.5	12.2	...	8.0	...	26.7	...	5890
11	6.5	11.5	2.2	4.0	19.8	22.0	3406	6210
12	6.9	11.5	1.3	2.6	19.5	21.0	3436	6280
13	6.3	11.2	4.0	8.0	19.8	25.5	3320	5920
15	−19.0	16.3	2.1	3.9	−0.6	1.2	3946	7800
16	6.0	15.1	1.9	3.2	23.0	24.7	3330	6000

* See Fig. 2.

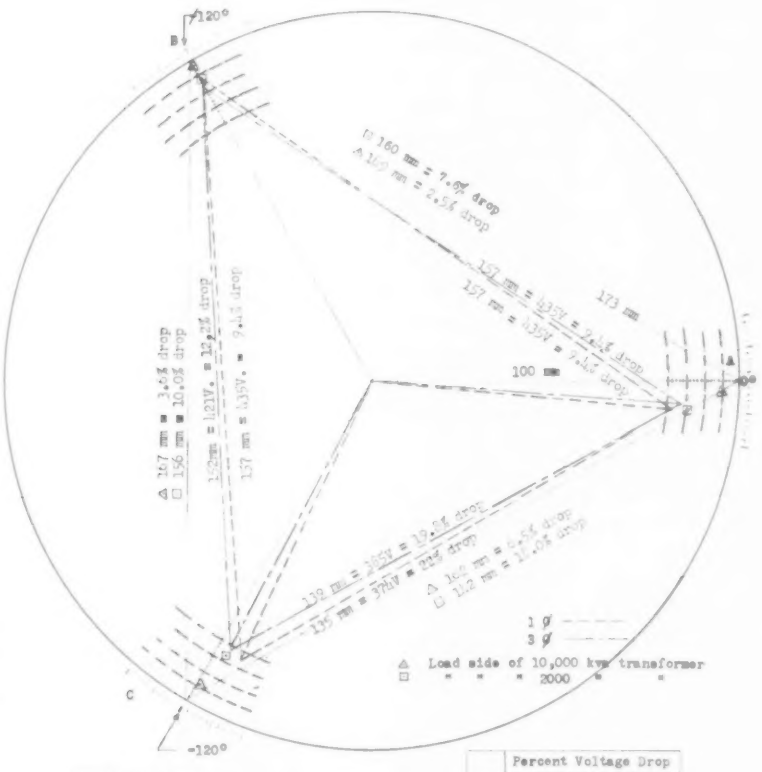
120°
B
160 mm = 7.6% drop
A 147 mm = 2.5% drop
157 mm = 4.3% = 2.4% drop
157 mm = 4.3% = 7.4% drop
173 mm
100 mm
A 147 mm = 2.5% drop
□ 156 mm = 10.0% drop
152mm = 4.2% = 12.2% drop
157 mm = 4.3% = 9.4% drop
132 mm = 3.6% = 19.8% drop
135 mm = 3.7% = 22% drop
A 160 mm = 6.5% drop
□ 162 mm = 17.0% drop
1 φ
3 φ
△ Load side of 10,000 kva transformer
□ " " " 2000 " "
C
A
-120°

Fig. 9 Three-phase vector diagram showing voltage levels determined in a-c network analyzer test 11

Load Conditions:
4000A 3φ load at point A (Fig. 2)
8000A 1φ load at point B (Fig. 2)
.3 PF

	Percent Voltage Drop	
	4000A 3φ	8000A 1φ
AB	9.4 %	9.4 %
BC	12.2 %	9.4 %
CA	19.8 %	22.0 %

Case 8. Apply 1 — 8000 A 1ϕ load at point B 0.50 PF.

Case 9. Apply 1 — 8000 A 1ϕ load at point B 0.70 PF.

Case 10. Connect busway radial with both loops open. Apply 8000 A load 1ϕ 0.3 PF.

Case 11. Apply 1–4000 A 3ϕ load at point A and 1–8000 A 1ϕ at B 0.3 PF.

Case 12. Repeat Case 11 with length of busway changed from 400 to 200 ft.

Case 13. Add 80 ft Current Limiting Busway between the 2–2000-kva transformers. Apply 1–4000 A 3ϕ 0.3 PF load on one transformer. Apply 1–8000 A 1ϕ 0.3 PF load on other transformer.

Case 14. Apply fault at 10–12–14 on Case 13 with loads connected.

Case 15. Insert series capacitor on secondary of 10,000-kva transformer, repeating Case 11.

Case 16. Repeat Case 11 with 1500-kva transformers.

The results of the network analyzer tests were in close agreement with calculated values of short-circuit current and voltage drop. Valuable information was obtained from the tests to aid in making decisions on the design of future systems. As an example, test number 15 indicates that series capacitors can be used to reduce, or even nullify, the voltage drops in transformers and feeder busways. The tests show the advantage of the double loop system of busways in reducing the voltage drop, providing additional current carrying ability (because of the parallel runs) or providing greater flexibility in firing the welders or in their location around the loops; and even in providing better selectivity between feeder and main circuit breakers.

Although it is not the purpose of this paper to present in detail an analysis of these tests, Table 4 shows the voltage-drop values for certain selected loads placed at the mid-points of the busway loops.

The tests using combinations of heavy single-phase welder load currents superimposed on the busway system at the same time it is carrying balanced 3-phase currents are interesting. They prove that the voltage drop under these conditions can be calculated with sufficient accuracy by the arithmetical addition of the voltage drop determined by the busway manufacturer's literature for the 3-phase current and that for the single-phase current. Obviously the 3-phase voltage-drop tables must be used to determine the drop due to the balanced 3-phase current and the single-phase tables for the single-phase current. Complications may arise in some types of busways, making it neces-

sary for the manufacturer to provide a third set of tables showing the voltage drop values for a single-phase current on one phase of a 3-phase busway. In the LVDP busway used on this job, this voltage-drop value happens to be the same as the values for single-phase currents on a single-phase busway.

Illustrative of the data or information obtained from the a-c network analyzer tests is the 3-phase vector diagram shown in Fig. 9 for Case 11. On this test the single-phase current of 8000 amp, in addition to the 3-phase current of 4000 amp, exceeds the maximum values anticipated in actual production but it makes a good example since the voltage-drop values are exaggerated (unusually large). The single-phase load of 8000 amp is connected to phase conductors A and C.

The result is 6.5% drop in the 10,000-kva transformer, 18% drop in the 2000-kva transformer and about 4% drop in the busway, making a total voltage drop in phase AC of 22%.

Conclusions

It is believed that the method used, both in the example in the paper and for the Twinsburg system, is very effective in selecting the proper system elements and it takes many factors into consideration.

1. It provides system elements adequate to satisfy the thermal requirements, voltage-drop requirements, short-circuit requirements with protective devices that will coordinate properly, providing selectivity and high speed tripping for both the maximum values of short-circuit current and the minimum values of arcing fault current. This provides greatly increased protection for the equipment since the damage done by arcing faults is a function of the arcing time. More important, it provides greater safety to electricians working with the equipment.

2. The use of the probability curves permits the selection of transformers, cables or busways with smaller ratings than would be required otherwise.

3. The double parallel loops of plug-in busways provide parallel paths for the welding current, effectively increasing the busway's current-carrying ability, and reducing the voltage drop in both the busways and transformers. It also makes it easier to obtain selectivity between the main and feeder circuit breakers.

4. The new plug-in busways used to feed the heavy welding departments are ideally suited for this application. They have adequate short-circuit strength, and the voltage drop is reduced to almost half that of conventional plug-in busways.

5. Series capacitors can be used to nullify partially or completely the voltage drop in transformers and also in feeder busways.

6. Vector-algebraic calculations of short-circuit current values and current division around the parallel paths in the busway loops or an a-c network analyzer study is necessary in order to select properly system elements.

Acknowledgment

The authors acknowledge the work and helpful suggestions of John Hamilton, R. H. Kaufmann, W. E. Long and Heinrich Hansen of the General Electric Co., and V. C. Aderente of Albert Kahn Associated (Engineers).

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THE GAMMA RADIOGRAPHIC CONTROL OF WELDED TRANSMISSION LINES

Paper by C. C. Bates was published in the November 1955 issue of The Welding Journal, 34, 1081-1096.

DISCUSSION BY FRANK C. PARKER

The author concludes his excellent paper with the statement: ". . . it should be possible in the future to ultrasonically examine the majority of welded joints in transmission lines at greater speeds than is possible today." He does, however, possibly create some confusion in the minds of American readers by having previously stated: "Difficulty was also experienced in differentiating between lack of root penetration and excess penetration as is schematically shown in Fig. 21."

The difficulty in such interpretations is not experienced in the United States where 31-deg angle wedges are used for such work. The clarity is illustrated in Fig. D-1.

It is possible that the accessories used by the author did not give a clear response. In this country, a

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31- to 36-deg angle wedge is used which results in an incident shear wave into steel at 40 to 45 deg. The 45 deg is optimum.

AUTHOR'S CLOSURE

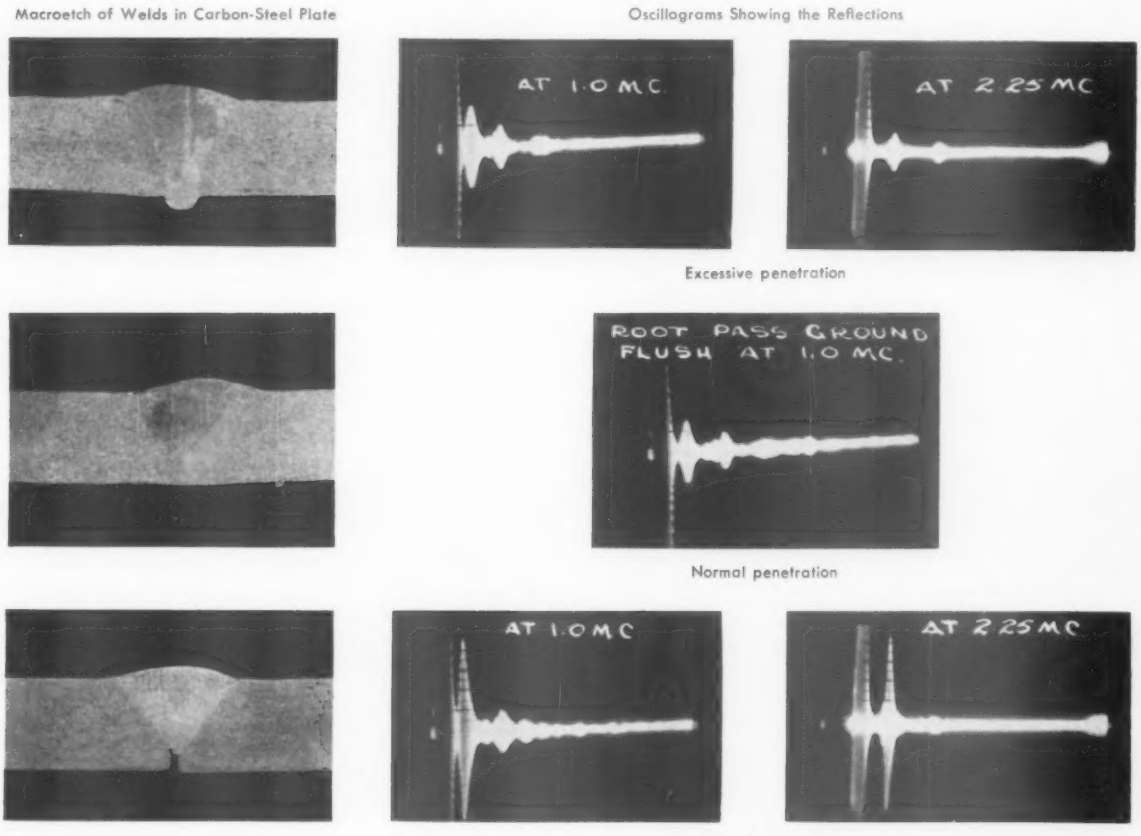
The author thanks Frank C. Parker for his constructive contribution to the discussion and in reply would comment:

It is interesting to note that using the 31–36-deg angle wedge producing an incidental shear wave at 40–45 deg produced such a very clear response on the oscilloscope.

As reported in the paper, we used a 20 deg transverse wave probe and also achieved a very clear response; but it will be appreciated that although we found satisfactory results in laboratory and factory conditions, under field conditions—which are far from ideal—we found the point made by the author to be the case and as such reported upon it. Further, we reported that shallower angle probes might have solved this problem but as the pipes involved were factory bitumen coated, this use of shallower angle wave probes was neither economical nor practicable under the circumstances.

The author never intended to convey, in the paper, that the use of ultrasonics was negative. Rather, at the expense of repitition, he would repeat his final conclusion in so far that "coupled with a cross check percentage of gamma radiography and with further research and development in conjunction with the equipment manufacturers it should be possible, in the future, to examine ultrasonically the majority of welded joints in transmission lines at greater speeds than it is possible today."

In conclusion, the author in thanking Mr. Parker for his constructive contribution to the discussion, would stress the obvious desirability of the fact that the use of nondestructive testing equipment should always be in the hands of an experienced and competent authority, as it is possible that even with the 31-deg angle wedges used by Mr. Parker, twin defects in a weld could be such that one would superimpose its image over that of the other, and therefore an erroneous reading on the oscilloscope might be obtained.



	Wave	*Sweep length*	*Pulse length*	*Pulse tuning*	*Frequency mc*	*Sensitivity*
Instrument settings for Sperry, Type UR, reflectoscope	Shear	5.1	10.0	6.8	1.0 2.15	0.8

Figure D-1

$11.35 SPENT FOR NICKEL-CORE ELECTRODE SAVES $1600 IRON CASTING

BY HARRY PEACOR

This story stems from abnormal conditions subjecting equipment to tremendous shock and strain. Such often happens to earthmoving equipment ... happened to a crawler tractor that landed for repairs and reconditioning at Shepherd Machinery Company of Los Angeles, Calif.

The casting was the final drive housing. It was cracked and broken. Cost for a new replacement would have been $1600 plus freight from the factory. But machinery firms buying, reconditioning and reselling used equipment do not live and prosper by junking broken parts and replacing them with new ones. They depend, perhaps more than any other type of business, on finding and using new and better ways to make broken and worn parts as good as new or better than new.

Until about two years ago Shepherd Machinery, as was common throughout the trade, had been brazing broken iron castings. This was necessitating complete disassembly and preheating, which along with rising labor costs was narrowing their margin of profit. They began searching for a better and less costly way ...

Harry Peacor is Regional Manager, All-State Welding Alloys Co., Inc., White Plains, N. Y.

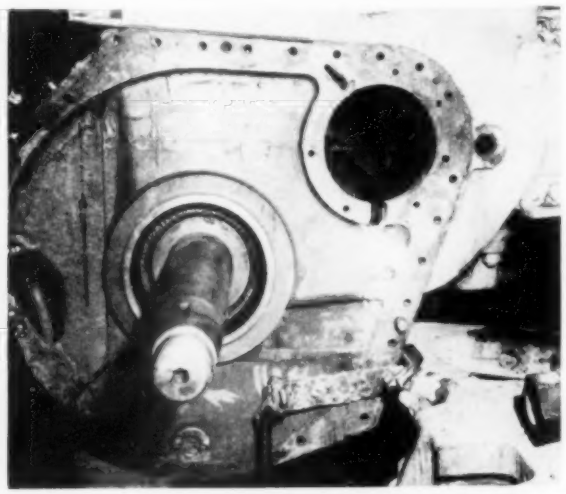


Fig. 1 Seriousness of breaks on right side of $1600 final drive housing of crawler tractor. Repairs were made without complete disassembly. Here cracks have been vee-ed and flame-cleaned of oil and grease. One welding pass has been made

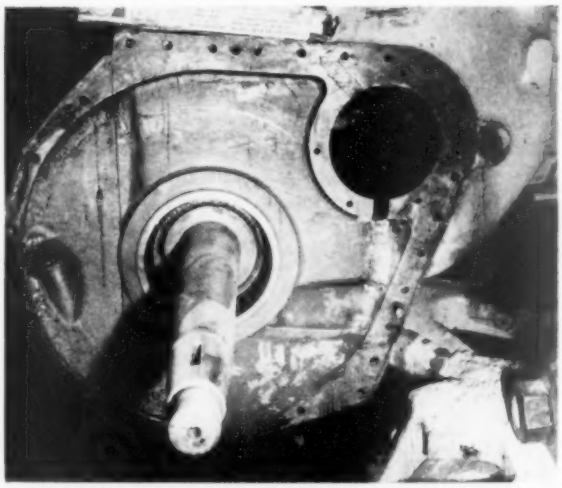


Fig. 2 Right side cracks in final drive housing have been welded in place and the welds are ready for final finish

decided to try arc welding. The first trials didn't satisfy them. Deposits were too porous. They were not fully machinable. There was underbead cracking, which caused leaks. Welds lacked required strength.

These were the circumstances when they were ready to tackle the final drive housing in 1954. They decided to seek technical help from their welding supply house. The accompanying pictures (see Figs. 1 to 4) were made on that occasion. They show the nature of the breaks, which were not confined to any given area. The results were excellent. The tractor has been in use ever since. In so far as the final drive housing is concerned, it should remain in use until or unless there is another accident of the kind experienced before.

The electrode selected was one designed to weld on cast iron at extremely low amperage. It could be used on either a-c or d-c current and could be obtained in all standard core sizes. Several of its characteristics made it particularly appealing for the job at hand. It was fully machinable ... practically free of spatter... and in its $^{3}/_{32}$-in. core size could be applied with 40 amp. Due to the extent of the breaks to be repaired, it was very important to pour the least possible amount of heat into the casting so as to minimize the chances of distortion. Five pounds of this electrode completed the job. Electrode cost totalled $11.35. Other items in *job* cost included partial disassembly, preparation of the cracks, lineup and clamping, welding, peening,

Fig. 3 Welding under way on left side of final drive housing on crawler tractor. Low amperage nickel-core electrode enabled welding in place without preheating

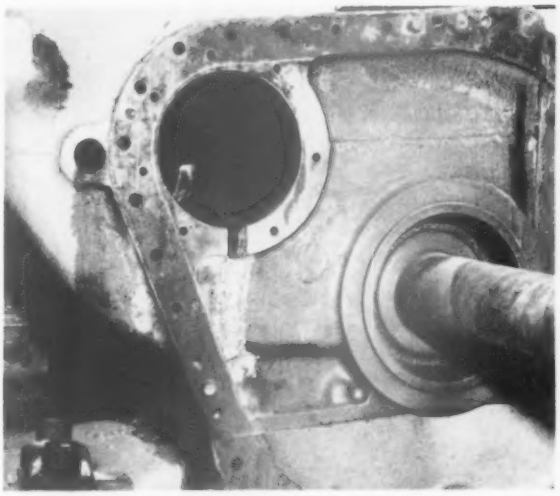


Fig. 4 Completed weld on left side. Electrode cost for total repair both sides was only $11.35

machining, painting and reassembly. And, as always, there was a charge for the welding machine, fuel and consumed supplies. All these items together added $335. Of the over-all job cost it is worth noting that the electrode cost was about 3%. Yet, it was this 3% that enabled the success.

A pneumatic chipper was used to vee the cracks. Standard practices of lineup and clamping were followed. Surfaces to be welded were cleaned of all sand, dirt, oil and grease. The latter was removed by heating with air-acetylene flame to 700° F.

Maximum penetration was desired along with low amperage. Hence, d-c reverse polarity was decided upon. Welds were peened between passes. Flux residue was removed with a wire brush.

As is evident in the pictures there were breaks on both the right side and the left side. Passes were alternated between the sides as a precautionary measure against distortion. This did not seem to be necessary, but was done anyway.

IRON-POWDER ELECTRODES CUT WELDING TIME ON FORK-TRUCK FRAMES

BY RAY ZEH

Lift trucks, built by the Automatic Transportation Co., Division of Yale & Towne Manufacturing Co., at its Chicago plant, are designed with a welded steel frame to carry the normally high loading stresses encountered in service.

Assembly of the frame components is greatly facilitated by use of the trunnioned fixture, shown in Fig. 1. It insures correct relative location of the components employed and also facilitates the welding because the fixture can be turned and locked in any of several angular positions, these being such that all welds are accessible and can be made in the most convenient downhand position. Positioning makes it possible to use iron-powder type electrodes which result in higher welding speed.

After tacking, joints are welded with an E-6024 electrode—$^{3}/_{16}$ in. diam.

Figure 1 shows a partly completed frame weldment for a model C. F. truck in the trunnioned fixture, at the left end of which there is a socket wrench for locking the fixture in the various desired positions. Fixture construction is such that, when welding is completed, the weldment can be removed by a crane or by a fork truck. Some welds, especially in areas not accessible when the weldment is in the fixture, are made after removing the weldment. When completed, the weldment appears as in Fig. 2.

Total welding time per frame approximates $5^{1}/_{2}$ hr

Ray Zeh is District Engineer associated with the Lincoln Electric Co., Cleveland, Ohio.

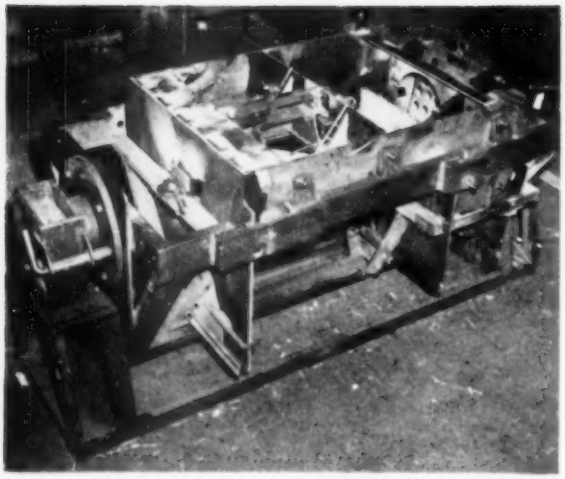


Fig. 1 Trunnioned fixture in which lift truck frames are arc welded, using an E-6024 electrode. A partly completed frame is shown in place

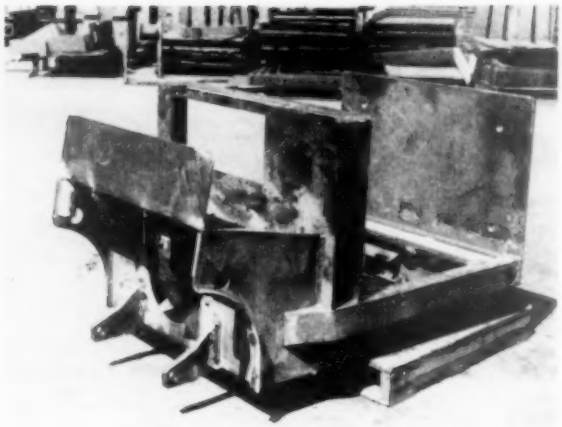


Fig. 2 Completed frame weldment produced in the fixture, Fig. 1. Use of this fixture and of iron-powder electrodes have reduced welding time to 5½ hr per assembly

or some 20% less than when other than iron-powder electrodes were used. This saving is reduced somewhat by the fact that the average length of welds is fairly short.

CYLINDER CARE CUTS COSTS

Oxygen cylinders and acetylene cylinders are built to stand rugged use. But they shouldn't be bounced around, handled carelessly, or misused. Here are some points to remember in protecting these expensive containers.

If you have to move cylinders a considerable distance, use a cylinder truck equipped with a chain or other steadying device to prevent them from being knocked over (Fig. 1). When you lift cylinders vertically or transport them short distances, use a cradle, boat, or suitable platform for use with a hoist (Fig. 2). Never use slings or electric magnets.

Don't Wrestle with Cylinders

When you move a cylinder by hand, tilt it and roll it on its bottom edge (Fig. 3). Dragging or sliding a cylinder is a bad practice and requires much needless effort.

Oxygen and acetylene cylinders are designed for only one purpose—to contain gas safely. Don't risk cylinder damage by using them as rollers or supports. And remember: a falling cylinder can injure you or others and damage equipment.

Upright cylinders are serviceable cylinders. Keep them that way. Use a chain or piece of strong metal tape to secure cylinders to a wall post, cylinder truck, or other firm support.

Check the Caps

Before moving an oxygen cylinder, check the valve protection cap (Fig. 4). Don't depend on anyone else—they might be careless. Be sure the cap is on straight and hand-tighten it yourself. If you find a cylinder lying on its side: make sure the cap is tight, then grasp the cap and raise the cylinder to a standing position. Never use the cap to lift a cylinder clear of the floor.

If a cylinder valve can't be opened by hand, leave it alone. And if you receive a damaged cylinder, don't try to repair it yourself. Tag such a cylinder as defective to prevent somebody else from using it. Then notify your supplier; he'll replace it with a cylinder in proper working condition.

Keep oxygen cylinders away from oily or greasy substances; never leave them where oil or grease can fall on them; and don't handle them with oily hands or

Based on a story by the Linde Co., New York, N. Y.

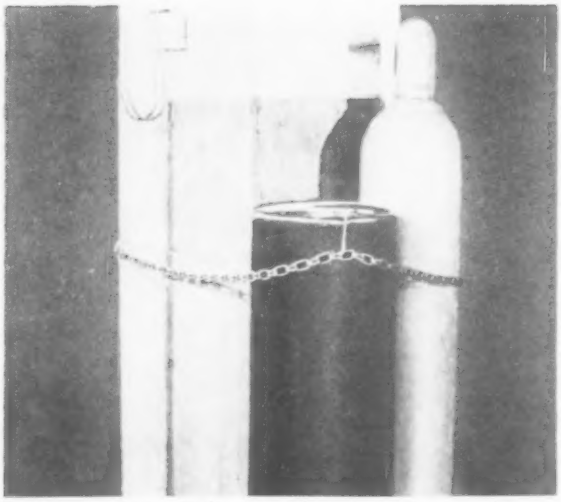


Fig. 1 Anchor cylinders upright. A hook over the top edge of the acetylene cylinder will prevent the chain from slipping

Fig. 2 Safely transport cylinders in a cradle. Chain the cylinders together to keep them upright

gloves. Oxygen won't burn, but it supports and accelerates combustion—causing flammable materials to burn with great intensity.

Arc Burns Can Ruin Cylinders

One of the most common causes of cylinder damage is arc burning. Yet, with a little thought and care, arc-burning can be eliminated completely—and you'll do away with the expense of testing, reconditioning, or replacing arc-burned cylinders.

Fig. 3 Don't drag a cylinder. Move it easily by tilting it and rolling it on its bottom edge

Arc burns are caused by a current passing through a grounded cylinder. Remember to keep your electrode holder, arc, and any source of current away from cylinders. If this isn't practical, use a suitable guard between the cylinders and the work.

Also keep your cylinders away from work tables and welding fixtures; be careful of how and where the work is grounded so that the ground connections never touch the cylinders; and make certain that the cylinders themselves are never grounded—insulate them with wood or rubber.

When you finish a job, be sure to close the cylinder valves. Make it a habit—it'll save worry for you and money and trouble for the shop.

Remember: cylinder care pays off. It eliminates repair costs, and makes more cylinders available to supply you with oxygen and acetylene—when you want them.

Fig. 4 Check the valve protection cap on your oxygen cylinders to make sure they're on straight and are hand-tight

Society News

District 1 Sponsors New England Regional Conference on Welding

The second Annual Conference on Welding sponsored by the Sections in District 1 was held in Boston on the 18th of September.

The day-long program consisted of six technical sessions each presided over by a recognized expert in a particular phase of welding or brazing. The 110 members and guests were enthusiastic in their reception to the speakers' approach to the various subjects presented, and spirited question-and-answer periods followed.

A paper on "The Union-Arc Process" was delivered by J. E. Dato AWS, of the Linde Co. "Magnetic Force Welding" was the subject of a delivery by Arthur Schueler AWS, of the Precision Welder & Flexopress Corp., and a paper on "Brazing Stainless Steels for High Temperature Service," was presented by Robert L. Peaslee AWS, of the Wall Colmonoy Corp.

Luncheon and Council meeting at the Sheraton Plaza Hotel followed the morning program.

Three more papers were presented at the afternoon technical session as follows: "Automatic Welding of Small Turbine Wheels" was covered by Ernest W. Jamison of the General Electric Co.; "Why Weldments Fail" was discussed by Helmut Thielsch AWS, of the Grinnell Co.; and "Problems Associated with Welding of Aluminum in Missile Applications" was given by William A. Wilson AWS, of the Army Ballistics Missile Agency.

A social hour and banquet followed, with Section Chairman Harvey S. Miller as toastmaster. Seated at the speaker's table were National President C. P. Sander; National Secretary F. L. Plummer; Director, District One, Sidney Low; and T. B. Jefferson AWS, Editor of "The Welding Engineer," who was the featured speaker. Mr. Jefferson gave an interesting, humorous, but highly thought-provoking speech on "The Future of Welding," in which he traced the growth of the industry from the early part of the century, up through the present and on into the future.

AWS Loses A Great Champion

Marguerite M. Kelly Dies After Heart Attack

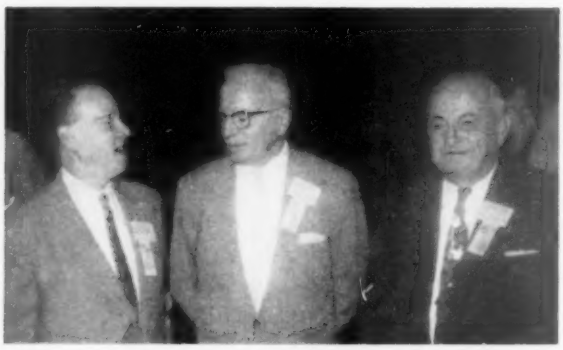
On October 22, the distressing news reached AWS headquarters that Miss Marguerite M. Kelly, Secretary Emeritus of the American Welding Society, had passed away earlier in the day, after being stricken by a heart attack.

Printer deadlines make it impossible to publish more complete details in this issue, but a fitting tribute to this dear friend will appear in the December Journal.

The Editors

AT THE NEW ENGLAND REGIONAL CONFERENCE IN BOSTON

Among the participants at the second annual conference sponsored by District 1 were (*left to right*): E. W. Jamison, R. L. Peaslee, H. Thielsch, A. J. Rosenberg, J. E. Dato, W. A. Wilson and A. Schueler



The honored guests and featured speakers included (*left to right*): Secretary F. L. Plummer, T. B. Jefferson and President C. P. Sander

THINGS YOU SHOULD KNOW

(That Happened in September)

• Second Vice-President C. I. MacGuffie spent September 4th with your SOCIETY Secretary reviewing names of companies which would benefit from the establishment of a Welding Information Center at SOCIETY Headquarters to aid in collecting and widely disseminating information about new developments in the use of welding. Members of his committee on Welding Information, a subcommittee of your Manufacturers' Committee, are actively seeking funds so that this program may be initiated at the beginning of 1958.

• On September 11th, your Secretary presented a technical talk before members of the Stark Central Section, meeting in Canton, Ohio, with Chairman Bill Evans, of the Morgan Engineering Co., presiding. The large and enthusiastic group which gathered at Mergus Restaurant gave ample evidence of the vitality of this young section. Bill was looking forward to a European trip which includes a business stop at Trieste, Italy. Your Secretary was welcomed by Frank Howard, President of The Welders Supply Co., after being met at the airport by Mr. Smith, one of his staff men. Following a drive to Cleveland with W. J. Fauser of Scott-Tarbell and a few hours in the Cleveland Hotel, your Secretary held conferences with staff members of ASM concerning the 2nd World Metallurgical Congress to be held in Chicago early in November.

President C. P. Sander devoted full time during the period September 15th to 28th to activities of your SOCIETY. On Monday, September 16th, he and your Secretary attended a meeting of your Headquarters Housing Committee called by Past-President J. H. Humberstone to consider costs and relative advantages of headquarter facilities at different locations; a meeting of your National Papers Committee with Chairman Tom Armstrong in charge, at which papers were selected for presentation at the Annual Meeting to be held in St. Louis next April (more than double the required number of suitable papers were submitted for consideration by this committee); and a reception and sectional meeting of NWSA.

The following day included attendance at a design conference and luncheon sponsored by Alcoa with your Secretary as member of a technical panel; and meetings of the Fabrication Division and Executive Committee of PVRC.

Wednesday activities included the annual all day meeting and luncheon of the PVRC Main Committee with your Secretary acting as Chairman; and a late afternoon flight to Boston to join members of our New England Sections at the Second New England Welding Conference. H. S. Miller furnished transportation from and to the airport and efficiently presided at the social hour and banquet at which President Sander, District Director Sidney Low and your Secretary spoke briefly before Ted Jefferson presented an excellent talk on "The Future of Welding." Another flight returned your President and Secretary to New York for a few hours sleep before starting an all day meeting of your Technical Council on Thursday.

At this meeting with First Vice-President G. O. Hoglund in charge, and with Art Kugler, Chairman TAC, and C. E. Jackson, Chairman EAC, in attendance, J. F. Lincoln, President of Lincoln Electric Co., discussed written regulations that are concerned with weld quality. He emphasized the necessity of continuously reviewing such codes and specifications to determine if requirements are proper and based on sound scientific facts which have been substantiated by actual tests. If not, they should be revised. Mr. Lincoln expressed the opinion that manufacturers would be willing to sponsor any research necessary to determine basis for such revisions and cited as an example the comprehensive studies on porosity recently completed at Ohio State University under the sponsorship of his company. It was agreed that SOCIETY committees should, whenever possible, review standards, determine any information needed, seek industry assistance in finding basic information, and then rewrite and simplify codes where evidence indicates this can and should be done.

The Technical Council considered data submitted by Assistant Treasurer Frank Mooney and Technical Secretary Ed Fenton covering the costs of producing the various AWS technical publications and adopted recommendations covering pricing policy on AWS publications, including a schedule of discounts to members, sections, book sellers, educational groups and others.

EAC Chairman C. E. Jackson and Handbook Editor Art Phillips outlined activities in these fields, and presented copies of the new first section of the Handbook and of a report on the educational symposium held last April in Philadelphia. The second section of the Handbook is now being prepared and will be sent to members next year. Following this pattern, members will receive a new five hundred plus-page section of the Handbook each year.

On Friday, September 20th, President Sander, First Vice-President Hog-

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	F. H. Dill	J. H. Blankenbuehler	J. F. Deffenbaugh
	E. D. Peters	G. E. Linnert	A. E. Pearson
	J. L. Wilson	P. G. Parks	C. M. Styer
	R. J. Yarrow	F. H. Stevenson	R. M. Wilson, Jr.

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District No. 2 • Middle Eastern D. B. Howard	*District No. 8 • Midwest* F. G. Singleton
District No. 3 • North Central H. E. Miller	*District No. 9 • Southwest* P. V. Pennybacker
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Junior Past-President F. L. Plummer	*Junior Past-President* J. J. Chyle

lund, EAC Chairman Jackson and your Secretary flew to Buffalo for a conference with top officials of the Canadian Welding Society who are planning a major reorganization of their society and wish to establish closer relations with AWS. "Is" Morrison welcomed your officers to Buffalo and furnished transportation to and from the airport.

President Sander joined your Secretary and Mrs. Plummer for the weekend at their home in Stamford, Conn., where they occupy a suite in the Town House at 65 Prospect Street.

During the following week President Sander and your Secretary enjoyed the unexcelled hospitality of Texans at Corpus Christi, Galveston, Houston, Beaumont, San Antonio and Austin, in spite of record breaking rains which fell almost continuously throughout the week. Each night, at well attended dinner meetings, President Sander presented a talk outlining SOCIETY activities and achievements. This was followed by a technical talk given by your Secretary.

At Corpus Christi, Alto Webb and Henry De Ville acted as special hosts for the meeting at Pike Grill and provided transportation which included a plant visit to Southwestern Oil and Refinery and a tour of this lovely and fast growing industrial area. Roy Pringle and Hubert Crick drove us from Houston to Galveston where John J. Kane and M. J. Bertini conducted the meeting, after which President Sander installed Don Allsen as new Chairman of the Division. In Houston, Pringle and Crick gave us a complete all day industrial tour of the area including plant inspections of Wyatt Metal and Boiler Works, where Jim Earthman acted as host, and of Mosher Steel Co. with which Crick is associated. A luncheon meeting of the Houston Section officers was followed by the evening dinner meeting of the Section at the Ben Milam Hotel with Chairman Roy Pringle in charge.

Another full day in the Beaumont-Orange-Port Arthur area, following a 6:00 A.M. departure from Houston, included plant visits to American Bridge Co. and Levingston Shipbuilding Co. at Orange, a general tour of the many chemical and petroleum plants, a luncheon at Orange and the dinner meeting at the new Ridgewood Motor Hotel at Beaumont amid delightful surroundings with a fine group of interested men representing the various important industries concentrated in this area. Bill Brandt of Big Three Welding Equipment Co. was a most gracious and generous host, and Paul Reitz, Chairman of the Division, handled the meeting and welcomed us to Levingston Shipbuilding where we saw a barge launching and inspected huge offshore drilling platforms.

The program for Friday included a luncheon in San Antonio and a visit to Southwest Research Institute with Dr. E. Wenk, Jr. as host. Another airplane ride brought us to Austin and the dinner meeting at El Toro Cafe with many representatives from the State Highway Department (Texas is a leader in the construction of welded steel bridges) and the University (where important research in welding is conducted). Dan Harrell, Chairman of the Division, presided. We were sorry to miss Vice-Chairman Clarence Rea, who handled correspondence for this meeting but was unable to attend. District Director Percy Pennybacker, who had welcomed us to Texas at the Corpus Christi meeting, also attended this meeting and with Section officers accompanied us to the airport to wish us *bon voyage* on our flight to Dallas, where your Secretary left President Sander and headed East on a night flight. President Sander returned to Los Angeles the following day, completing a two week period which included a succession of long, fully scheduled days kept pleasant by the outstanding hospitality of those mentioned herein and many, many others to whom we also send our sincere thanks.

Fred L. Plummer

EAC DOINGS

Welding and Its Educational Levels

The symposium on education, held in April at the 38th Annual Convention of the AMERICAN WELDING SOCIETY, revealed some startling facts. It disclosed the danger the welding industry faces through lack of trained men and it indicated the inadequacies at all levels of scientific and engineering education.

A tape recording was made during the symposium. This has been edited and prepared for distribution to the educational representatives of each AWS section. Some sections are arranging a talk, based on the symposium report, at section meetings this fall. An open discussion following such a talk would be exceedingly valuable if it revealed the availability, quality and coverage of welding education locally.

Clarence Jackson, with his co-chairman H. A. Sosnin, presided at the symposium. Speakers included Dr. Howard Landis Bevis, chairman of the National Committee for the Development of Scientists and Engineers; M. M. Hanson of the U. S. Department of Labor; H. E. Baldwin of the Le Tourneau Westinghouse Co.; R. D. McCauley, associate professor of Welding Engineering at Ohio State University; and Dr. Howard Hogan, U. S. Department of Health, Education and Welfare.

Mr. Jackson opened proceedings by pointing out some of the vast changes which have taken place during the last fifty years: ice has been replaced by 40 million refrigerators; oranges, from a Christmas novelty, have become an everyday necessity; the horse and buggy has been replaced by 50 million automobiles and the livery stable by 100,000 gasoline stations.

This brought up the question as to whether our thinking had kept pace with these changed conditions.

It was pointed out that the Bureau of Census reports that we have approximately 300,000 welders in the United States. We could use another 100,000 if they were available. Within the next few years our needs will double. A statement by Dr. Abrams of the National Asscciation of Manufacturers indicates the magnitude of the shortage. In his address he states: "a nation whose entire material progress and existence depend upon science and engineering now finds itself desperately short of both."

Dr. Bevis pointed out that in the year 2000 there will be twice as many people in the U. S. as there are today. Our most valuable natural resource is people. Yet this increase in population is fast becoming a liability instead of an asset. Our material resources are

Prepared by Educational Activities Committee.

shrinking at an alarming rate and the only logical answer to the problem is education—trained men with the knowledge and skill to transmute our resources into more and better things.

Some interesting comparisons were drawn between Russia and ourselves. It was stated Russia has realized that military strength and economic strength are just two phases of the same thing. Without economic strength there can be no sustained military strength and education is the key to both. Having grasped this basic concept, Russia set up a system of learning in schools and laboratories.

This was started at least fifteen years ago!

Not only were teachers assigned to this project and students assigned to receive the tuition, but the whole project was made economically desirable. A level of economic subsistence has been provided which is considerably above that of other people.

In quantity the graduates outnumber our own. In quality we are in some doubt. It is always difficult to answer such a question. Results throw a certain amount of light on the subject. The Russians are turning out some pretty good airplanes; they are making some very adequate submarines; we know they have nuclear apparatus; and one important fact is becoming more and more evident—they have passed the stage where they have to rely upon foreigners.

Dr. Bevis proposed a long-range and a short-range objective. The long-range program would be the developing of trained engineers. This program would take many years to accomplish. The short-range program would involve the introduction of another classification—the technician, a man whose manipulative skill could be recognized in the same way that academic skill is recognized. This man would fill the gap between the graduate engineer and the skilled worker.

The importance of apprenticeship training was stressed by Mr. Hanson. He explained how employers and labor were helped by state apprenticeship agencies to develop apprentice training programs. The thinking among labor groups was clearly demonstrated by an extract from the A F of L report of 1955, "Welding is an example of a relatively new and growing operation applicable to all trades."

Example after example were given showing how great had been the growth and wide the recognition welding had received by apprenticeship programs. It was apparent that apprenticeship programs, in general, had moved with the times. The need for training in welding and related subjects had been seen and the programs expanded accordingly.

Prof. McCauley outlined the position the welding engineer must take in all phases of manufacture. He pointed out that a welding engineer must be a combined metallurgical engineer, civil engineer, mechanical engineer and electrical engineer who also possesses a grounding in nontechnical and cultural subjects.

Engineering in general and the welding industry in particular are not fully understood by the average student. By the time the prospective student has realized his field is engineering it is frequently too late to obtain the fundamental courses in mathematics and physics. Under our present educational structure, young men must elect engineering or science as a life's work prior to entering high school. The ground work must be done before entering college and must include mathematics, chemistry and physics.

Dr. Hogan, who had government statistics to back up his opinions, expressed the view that industry is eating its own seed corn. The science and mathematics instructors are being induced to enter industry by the offer of higher salaries. This robs the educational institution of its faculty.

One of the most successful approaches advocated was to stimulate motivation among the high school groups or the groups entering high school. This could be achieved by telling them the opportunities available in the welding industry and the importance of welding. If they could see its relation to their hobbies, their interests and the field they contemplated entering, it would do much to arouse a desire to enter the welding industry.

The symposium revealed the need for trained scientists and engineers. The speakers made it quite clear that the coming years would be critical ones—doubly so for those industries which required engineering skill. The solutions offered involved adequate education, apprenticeship training, a new classification of technician and, above all, a means of telling the youth of this country the opportunities available in the welding industry.

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Section News and Events

as reported to Catherine O'Leary

OUTING

Bridgeport, Conn.—On September 12th a "get acquainted" outing was held by the *Bridgeport* Section at Grassy Hill Park. This event took place at 5:30 P.M.—a "come as you are" affair—bringing one potential member as a guest. The attendees started to arrive at about 5:30 to a total of thirty men—including members. A catering service was employed for the serving of refreshments. The food was excellent. Games were participated in throughout the evening. The affair was a success and a good time was had by all.

Potential members were given the opportunity to view all available AWS literature and to talk to the members on the many benefits to be derived from membership in the SOCIETY.

WELDING PRESSURE VESSELS

Cincinnati, Ohio—The *Cincinnati* Section met on September 24th at the Engineering Society Headquarters. Speaker was Perry C. Arnold AWS, chief field welding engineer for the Chicago Bridge and Iron Co. Mr. Arnold's subject, "Field Welding of Pressure Vessels," is one in which he has had wide experience all over the world. His talk consisted of three parts. The first part was a film covering the welding of the housing for the atomic submarine reactor at Schenectady for the Knolls Atomic Power Laboratory. This spherical ball, known as a Hortonsphere, is 226 ft in diam. More than three miles of welds were made in the fabrication of the sphere, sixty percent by the automatic process and forty percent manually. The second portion of his talk covered other field welding applications, the types of base plate and welding electrodes used. He pointed out some of the welding problems encountered using T1 plate and cracking associated with inadequately dried electrodes.

The third portion of Mr. Arnold's talk covered the more technical aspects of welding heavy plate. He discussed the weldability tests and the tensile properties of weld metal for different electrodes. Mr. Arnold covered the various bend tests and impact tests on these materials.

JET ENGINE PARTS

Denver, Colo.—The *Colorado* Section held its first meeting of the 1957–58 season on September 10th in the Cattlemen's Room of the Old Windsor Hotel in Denver. The group got together for a social hour before dinner. The dinner itself was served "buffet" style and proved popular with the diners.

After dinner the group was addressed by Gordon Parks AWS, chief welding engineer of Solar Aircraft in Des Moines, Iowa. He discussed the many problems and their solutions which they encountered in the manufacture of aircraft jet engine components. He concentrated mostly on corrosion and heat-resistant metals such as stainless steel and titanium. Mr. Parks' talk was illustrated with slides and was very well received by the group.

SECTION MEETING CALENDAR

DECEMBER 2

LEHIGH VALLEY Section. Dinner 6:30 P.M. Meeting 8 P.M. Walp's Restaurant, Allentown, Pa. "Fundamentals of Arc Welding," C. E. Jackson, the Linde Co.

DECEMBER 5

NORTHERN NEW YORK Section. Dinner meeting 7:00 P.M. Panett's Restaurant. Technical meeting 8:00 P.M. "Industrial Hygiene and Welding Safety," John J. Ferry, General Electric Co.

DECEMBER 6

COLUMBUS Section. Riverside Rathskellar, Columbus, Ohio. Dinner 6:30 P.M. Meeting 8:00 P.M. "Tooling for Resistance Welding," Lyman Rouwe, Westinghouse Electric Corp. Also panel discussion of tooling problems.

NORTH CENTRAL OHIO Section. Findlay. Quiz. Bob Ellison, Chairman.

PHILADELPHIA Section. Engineers Club. 7:45 P.M. Panel Discussion: "Welding Inspection Problems."

DECEMBER 9

NORTHWEST Section. Elks Club, Minneapolis, Minn. Happy Half Hour 6:00 to 6:30 P.M. Dinner 6:30 P.M. "Resistance Welding," Ralph Wolfe, Minneapolis-Honeywell Reg. Co.

DECEMBER 10

NEW YORK Section. Victor's Restaurant, 1 E. 35 St., N.Y.C. Get-together 5:30 P.M. Dinner 6:00 P.M. Meeting 7:00 P.M. "Welded Structures," Solomon Sheer, Dept. of Buildings, City of New York.

DECEMBER 11

CLEVELAND Section. Manger Hotel, Cleveland, Ohio. Social hour 6:00 P.M. Dinner 6:30 P.M. Meeting 8:00 P.M. "Resistance Welding."

DECEMBER 12

MADISON Section. Eagles Club, Madison, Wis. "Welding Electrodes," Austin Hiller, General Electric Co.

MICHIANA Section. South Bend, Ind.

SAGINAW VALLEY Section. Dinner Meeting 7:15 P.M. Hi-Life Inn, Saginaw, Mich. Management Night. W. T. Gillespie, Dow Chemical Co.

DECEMBER 13

PHILADELPHIA Section. Engineers Club. 3:00 P.M. Joint meeting with Society of Naval Architects and Marine Engineers

DECEMBER 17

SAN ANTONIO Section 6:30 P.M. Youngblood's. San Antonio Bar Assn. to furnish speaker.

TOLEDO Section. Maumee River Yacht Club. Dinner 6:30 P.M. Meeting 8:00 P.M. "Stump the Experts" Program.

DECEMBER 18

PEORIA Section. Mecca Supper Club, Farmington Road, Peoria, Ill. Dinner 6:30 P.M. Meeting 7:45 P.M. "Job Shop Welding," James Bessler, Specialty Welding Co.

PROVIDENCE Section. Dinner meeting Johnson's Hummocks, 245 Allens Avenue, Providence, R. I. 6:15 P.M. "New Developments in Braze Welding, Brazing and Soldering," E. F. Garriott, Ampco Metal, Inc.

SOUTH FLORIDA Section. 8:00 P.M. Firemen's Benevolent Hall, Miami, Fla. "The Story of Nickel and Mining for Nickel" Panel Discussion.

Editor's Note. Notices for February 1958 meetings must reach Journal office prior to December 1, so that they may be published in January Calendar. Give full information concerning time, place, topic and speaker for each meeting.

SEMIAUTOMATIC WELDING

Detroit, Mich.—The officers and executive committee members of the *Detroit* Section held their August summer meeting aboard the Schooner "Cabot" with genial host and fellow board member Porter Strother. There was a well planned chicken dinner with plenty of coffee and refreshments, and a smooth sailing cruise on Lake St. Clair. A wonderful time was had by all, and those who missed this annual event lost out on a good time.

The regular meeting held on September 13th was well attended, with quite an interesting coffee talk on "What's Happening on our Doorstep," by Ellis Reed, director of Public Relations for Clark and Bobertz, Inc.

An equally interesting paper on "A New Semiautomatic Welding Process," was presented by R. A. Trentham, district engineer, Linde Co., Indianapolis. This talk was very well received.

On September 19th the Section held a special technical meeting on "Machine and Product Design for Multi-Spot Welding Machines." This subject was covered by F. A. "Dutch" Bodenheim of the Federal Welder & Machine Co.

These special meetings are growing in popularity, and to all the members and friends of the Section who are interested in automotive and resistance welding processes, an invitation is extended to attend future meetings.

NATIONAL ACTIVITIES

Houston, Tex.—The first fall meeting of the *Houston* Section was held on September 25th at the Ben Milam Hotel in Houston. A total of eighty members and guests were present.

This was quite an occasion since National President C. P. Sander and National Secretary F. L. Plummer provided the program for the evening.

The meeting was opened with a social hour during which "Highlights of the 1956 Southwest Football Games" were shown.

President Sander gave a very interesting report on "Activities of the National Society and Its Staff"; while Secretary Plummer presented a most entertaining and informative discourse on "Design for Welded Plate Fabrication."

Both officers made a one-week tour of the Texas Gulf Coast visiting the Corpus Christi Division, the Texas City Division, the Austin Division and the Beaumont Division, all of the Houston Section.

The members extended a Texas brand of hospitality to the distinguished visitors who are always welcome back to the Houston Section.

DEVELOPMENT OF WELDING

Des Moines, Iowa—The *Iowa* Sec-

HOUSTON SECTION OPENS FALL SEASON

Houston Section officers and directors with President C. P. Sander and Secretary F. L. Plummer. Seated (*left to right*) are: the Messrs. Potter, Wehner, Derden, Sander, Pringle, Plummer. Standing (*same order*), are: the Messrs. Ketchbaw, Hildebrand, Olson, Avis, Morgan, Manchester, Barbin, Crick and Middlehurst

Houston Section Chairman R. P. Pringle flanked by Secretary Plummer and President Sander

Secretary Plummer and President Sander shown with Beaumont Chairman P. F. Reitz

Some of the members and guests who attended the September 25th meeting of the Houston Section

HUMBERSTONE ADDRESSES IOWA SECTION

Past President Joseph H. Humberstone was the guest speaker at the September 19th meeting of the Iowa Section

Part of the large group that heard Past President Humberstone speak on "The Development of Welding for Engineering Fabrication"

tion opened its first meeting of the year on September 19th. The meeting was held at the Hotel Kirkwood with the usual superb buffet dinner. After the business meeting L. P. Faddis, chairman, turned the meeting over to Wayne Putman, executive committee member, who introduced the speaker, J. H. Humberstone, past president of the AWS.

Special invitations were extended to executive management of many Iowa companies and to the educators of the colleges in this area to hear the vital role welding is playing today and where it stands in the industrial future.

Mr. Humberstone's subject was "The Development of Welding for Engineering Fabrication" and his talk was illustrated by slides showing applications of welding in all phases of construction and manufacturing in the United States. He traced welding from World War I to the present-day nuclear-power developments. He stressed that mechanization of welding processes has become necessary not merely for high production and reduced costs per unit of output, but for quality as well. The ability of welding processes to meet the requirements imposed by supersonic, high-temperature service conditions in a wide variety of metals is now universally recognized in the aircraft industry.

Mr. Humberstone mentioned that the welding engineer provides the coordinating link between the activity embracing materials, design and methods of fabrication. Basically, our approach to current and future problems must be educational. He stated that all engineers, student and professional, regardless of their specialization, need now, more than ever before, a thorough background in the technology of welding.

SOCIAL MEETING

Kansas City, Mo.—The "kick-off" meeting of the 1957–58 season for the *Kansas City* Section was held on September 12th in the American Legion World War II Memorial Building. The emphasis of this meeting was entirely on getting people acquainted rather than a technical meeting. A fair-sized crowd of 53 attended the "mixer," dinner and film presentation. The new Section chairman, Blaine Harrington, welcomed the guests, discussed the activities for the year and urged them to bring others to the meetings and make the coming year a big one.

WELDING PROCESSES

Madison, Wis.—The first meeting of the *Madison* Section for the 1957–58 season, the fourth year of its existence, took place on September 12th at the Eagle's Club in Madison. The membership of this Section has risen to 116 members and numerous prospects for the new year are available.

A good talk was given by Orville T. Barnett AWS, assistant manager, Metals Research, Armour Research Foundation, Chicago. Mr. Barnett discussed all the major welding processes and their relative popularity and the reasons behind this.

INSPECTION TOUR

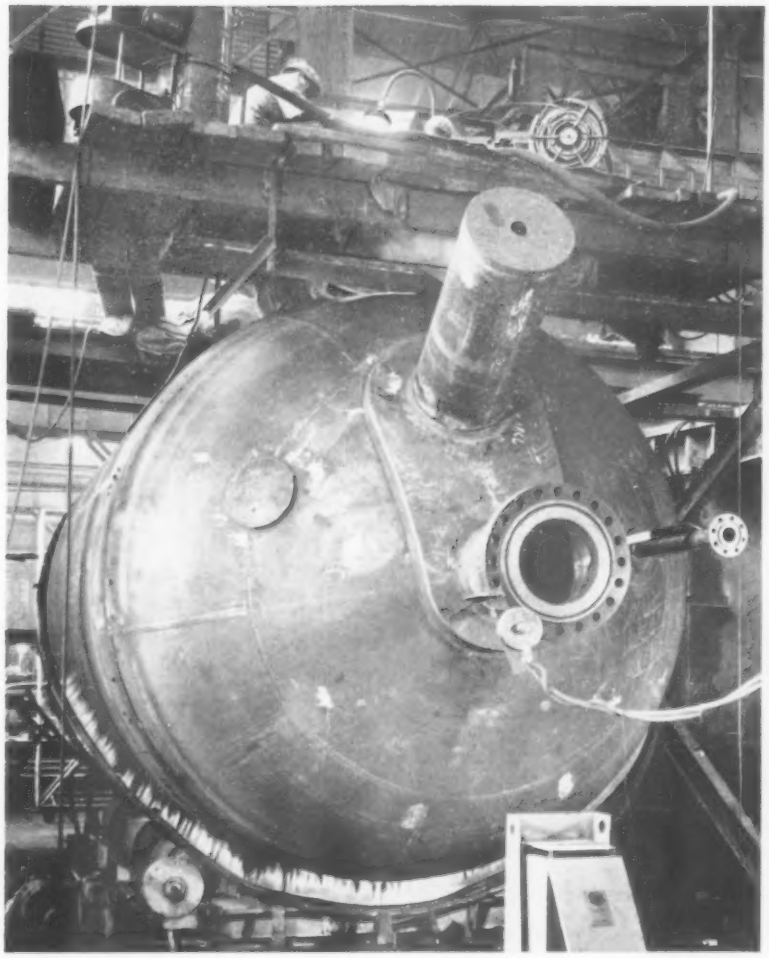
Baltimore, Md.—On the morning of Saturday, September 21st, 123 members and guests of the *Maryland* Section gathered at the Fairfield entrance to the Baltimore Harbour Vehicular Tunnel for a guided tour of the tunnel, ventilation building and master control center. The group was conducted through the tunnel by J. E. Greiner, who described the many interesting construction and operating features of the tunnel, the ventilation and control buildings and traffic control features. The tunnel and highway approaches are due to be open for traffic early in December 1957.

TOOL WELDING

South Bend, Ind.—The *Michiana* Section's 1957–58 season got under way on September 19th with a talk on "Tool Welding" by Frank Kessler AWS, Welding Equipment & Supply Co., Detroit, Mich. Mr. Kessler prefaced his talk with two film strips which laid the ground work for his remarks. These films showed types of weld repairs that can be made on tools and indicated the proper way to do them. Mr. Kessler emphasized the need for using the right procedure including pre- and post-heating, because of the extreme hardenability found in tool steels. Selection of a filler metal to repair a given job is

MARYLAND SECTION TOURS VEHICULAR TUNNEL

Members and guests of the Maryland Section shown during their tour of the Baltimore Harbour Vehicular Tunnel on September 21



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When inspection by X-ray is required, don't gamble . . . rewelding is expensive . . . specify Drawalloy "quality controlled" wire. *Drawalloy* stainless steel welding wire is produced to strictly controlled specifications to provide the right chemistry, finish and temper for smooth operation in your equipment and to provide X-ray quality welds.

Why not discuss your stainless welding wire needs with your *Drawalloy* Distributor or Representative . . . a man ready to help you. Bulletin 355-DC provides complete information on every grade of *Drawalloy* wire. Write to: Drawalloy Corporation, Lincoln Highway West at Alloy Street, York 13, Pennsylvania.

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NEW JERSEY SECTION PICNIC FEATURED BY HUGE TURNOUT

Steve Sullivan and Tommy Smith dispensing food and drinks at the September 21st picnic of the New Jersey Section. Some 793 members and guests attended this affair

The "Guess How Much" gate jack pot was won by A. Gontarz, extreme right. Section Chairman E. DiLiberti and Picnic Chairman A. C. Axtell made the presentation

Shot-putting contest

Horse-shoe pitching contest

Nail driving contest

dependent upon the analysis of the material to be welded. It is not necessary to match that analysis exactly, but the filler metal should be chosen whose heat treatment is the same as the base metal.

ALUMINUM WELDING

Milwaukee, Wis.—The *Milwaukee* Section opened its 1957–58 season with a smorgasbord dinner on Friday, September 20th at the Ambassador Hotel with 108 in attendance. During the business meeting, thirty-four new members gained since the April meeting were welcomed by the Section.

Technical speaker for the evening was Howard E. Adkins AWS, of Kaiser Aluminum and Chemical, Inc., who gave a fine talk on "The Practical Aspects of Aluminum Welding." His talk covered inert-gas-shielded, tungsten-arc and metal-arc welding of aluminum with emphasis on the proper selection of the base material for the job, selection of the wire to match the base material, and the importance of keeping the base material and wire clean. Proper arc voltage, clean and dry base material and wire, and welding as fast as possible were given as means of controlling porosity in welds. His talk was accompanied with slides and closed with the showing of an excellent film entitled "High Speed Aluminum Welding."

Preceding the technical meeting, Charlie Blossfield, assistant ticket director of the Milwaukee Braves, told the inside story of the Braves.

ANNUAL PICNIC

Union, N. J.—Seven hundred and ninety-three members and guests attended the *New Jersey* Section's annual picnic held at the Old Cider Mill Grove in Union, N. J., on September 21st.

Door prizes to a value of over twelve hundred dollars contributed by companies interested in and associated with welding were distributed to winning ticket holders. A fish bowl containing two hundred and seventy-three dollars and change, known as the "Guess How Much Gate Jack Pot" was won by A. Gontarz whose guess was correct to the penny.

After filling themselves on frankfurters, hamburgers, roast beef, clams, corn and trimmings, washed down with unlimited amounts of beer, the boys participated in games of softball, shot-put, fly casting, horseshoe pitching, golf putting, nail driving and egg throwing.

Credit goes to Andy Axtell of the Essex Welding Equipment Co., and to his committee for the huge success of the greatest of all picnics sponsored by the New Jersey Section.

INERT-GAS WELDING

New York, N. Y.—The first Fall meeting of the *New York* Section was held on September 11th. An interesting program had been arranged and the speaker of the evening was George Edwin Linnert AWS, research welding metallurgist for the Armco Steel Corp., Baltimore, Md.

Mr. Linnert's topic, "Inert-Gas-Shielded Welding" was well received as evidenced by the number of questions that were asked of the speaker after the talk. Discussed were the welding of recently developed precipitation hardening stainless steels, rimmed, galvanized and aluminized

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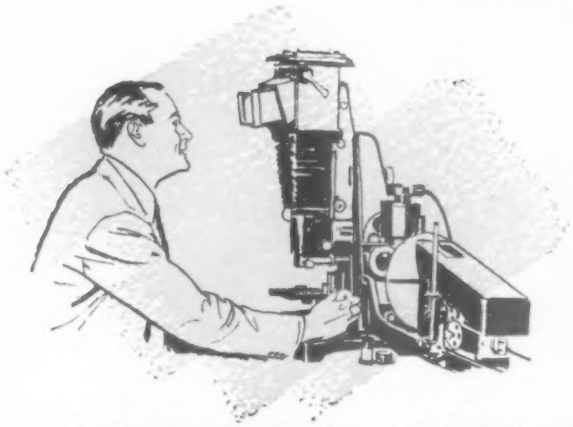

INDUSTRY'S MOST COMPLETE RESISTANCE WELDING APPLICATION RESEARCH FACILITIES

In response to industry's rapidly growing interest in resistance welding, the facilities of the Sciaky Research Division have been made available for contract research in the application of resistance welding.

These facilities include an experienced engineering staff, a complete range of the most advanced resistance welding machines including the largest spot welder in the world and a laboratory equipped for metallography, chemistry, electronics, photography and testing as applied to resistance welding.

Typical projects include: Coordination of design and production for resistance welding; research on the weldability of new metals; investigation of weldability and pilot run of new product; research to develop data for roll spot welding heavy gauges of aluminum.

If you have a fastening requirement, here is the place to determine objectively the feasibility of resistance welding. Send an outline of your problems and ask for the 20-page Research Division brochure. Sciaky Bros., Inc., 4919 W. 67th St., Chicago 38, Ill., POrtsmouth 7-5600.

The Sciaky Research Division is housed in this modern 15,000 sq. ft. building devoted exclusively to research in the application of resistance welding.

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steels. Mr. Linnert advised that most porosity found in stainless-steel welds made by the inert-gas-shielded process is due to hydrogen from moisture from a leaky torch.

The meeting was held at Victor's Restaurant, One E. 35th St., New York City, where an excellent dinner was served prior to the meeting.

WELDING SCIENCE

Kenmore, N. Y.—George E. Linnert AWS, of the Armco Research Laboratories, Baltimore, Md., was the speaker at the September 26th meeting of the *Niagara Frontier* Section held at the Continental Inn.

In his talk on "Welding—Art or Science?" Mr. Linnert described the troubles met by "artists" who welded materials on which they had too little technical information. Mr. Linnert, as a welding metallurgist, spends much of his time troubleshooting on problems that, in his opinion, should never have happened.

Many fabricators, for example, are unaware that stainless steel is ruined by heating (welding or annealing) in the presence of sulfur, zinc or carbon. Zinc picked up from shears previously used on galvanized iron has caused stainless to crack in a spectacular manner while welding.

In another case, zinc oxide from layout paint was the culprit. Sulfur (often from cutting oils), like zinc, causes cracking. Carbon (often picked up in a faulty annealing atmosphere) ruins the corrosion resistance, and on the heat-treatable grades, alters the response to heat treatment. Preventative measures are usually simple and are described in the literature of the manufacturers.

SPEAKERS AT "DREXEL NIGHT"

Principal speaker at the September 16th "Drexel Night" sponsored by the Philadelphia Section was G. E. Linnert. He spoke on "Welding the Metals of Tomorrow"

Clarence Jackson, chairman of AWS Educational Activities Committee, was the after-dinner speaker. He is shown above with Mr. Linnert

The speaker explained how hot cracking of stainless weld metal from grain boundary segregation was overcome with a filler metal compounded to give five percent ferrite in the deposit.

Mr. Linnert's talk was illustrated by slides and a lively discussion followed.

AUTOMATION IN WELDING

Oak Ridge, Tenn.—The *Northeast Tennessee* Section opened its 1957–58 session with a dinner meeting at the Elk's Club on September 16th. A delicious dinner was enjoyed by thirty members and guests, followed by an interesting and informative address by Cecil C. Peck AWS, of the Cecil C. Peck Co., Cleveland, Ohio. The subject of Mr. Peck's talk was "Automation in Welding" and was accompanied by slides of the various types of automatic welding equipment manufactured by the company bearing his name.

Chairman W. J. Leonard outlined the slate of coming events for the new season which promises to be a membership booster and assures a successful year. The drawing of the door prize was followed by the usual friendly get-together.

RESISTANCE WELDING APPLICATIONS

Peoria, Ill.—Robert R. MacDonald, of Precision Welder & Flexopress Corp., gave a very interesting talk on Resistance Welding Applications at the September 18th meeting of the *Peoria* Section held at the Mecca Supper Club. There were seventy-five members in attendance, a good turn-out for the first meeting of the season.

ARCAIR PUTS PLANT IN OPERATION 19 HOURS FASTER

A large east coast manufacturer, plagued by an emergency plant shut-down, credits Arcair Torches and Copperclad Electrodes for lessening the down time by 19 hours. Stainless tube sheet 5" thick on a heat exchanger cracked and 100" of it had to be cut and replaced. Arcair Torches, ⅜" Arcair Copperclad Electrodes, ordinary air and DC welding machines and two operators—spelling each other—needed only 11 hours to cut the periphery versus an estimated 30 hours with conventional methods.

Using only an electric arc and compressed air, the Arcair Torch is the new, efficient and money-saving answer to most metal removing problems. Whether used as a production or maintenance tool, the patented Arcair Torch saves up to 60% over other metal removing methods. For top efficiency and savings, always use genuine Arcair Electrodes, plain or Copperclad, with your Arcair Torch.

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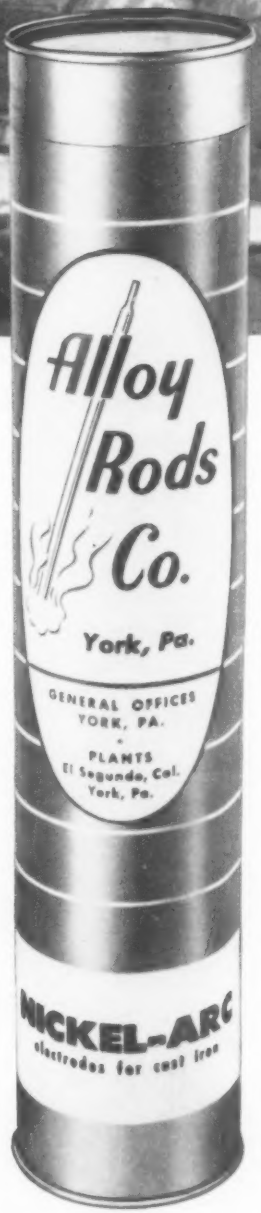

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Crack free welds . . . Not only single pass overlays or repairs—even multiple pass fillets and butt welds, and in complex assemblies too, Nickel-Arc welds are crack free.

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METALS OF TOMORROW

Philadelphia, Pa.—The Drexel Institute of Technology has opened its sixth season of courses in welding metallurgy and welding engineering, sponsored by the *Philadelphia* Section. The program was again inaugurated with a meeting in the Drexel auditorium on September 16th, following a dinner.

The coffee talk subjects were devoted to welding education. Rudi Guenzel, chairman of the Section Educational Committee, introduced Dean K. Riddle who greeted the group and outlined the objectives of Drexel's welding courses. The after-dinner speaker was Clarence E. Jackson, staff engineer of the Linde Co. Mr. Jackson reviewed the current activities of his national Educational Activities Committee and the work of several subcommittees which are actively establishing training schedules.

Byron Gates, Section chairman, presided over the technical meeting in the Drexel auditorium and introduced Dean Riddle who reiterated the objectives of the welding instruction at Drexel. Faculty members H. P. George, H. Pfeffer, R. W. Thomas and W. K. Scattergood were introduced. A more detailed description of the courses in welding metallurgy and welding engineering was presented.

The technical speaker of the evening, George E. Linnert (AWS), of the Armco Steel Corp. was presented by Vice-Chairman Carl M. Schaub. Mr. Linnert gave a very timely and interesting talk on "Welding the Metals of Tomorrow." Emphasis was placed on the new high-alloy steels to be welded rather than upon welding processes and techniques. Attention was called to the precipitation-hardening stainless steels which are being used in increasing quantities in airframes for new aircraft and missiles. The composition and properties were shown to influence strongly weldability. The welding of such materials was presented as a challenge to welding metallurgists and engineers.

PLANT VISITATION

Butler, Pa.—On September 20th, the *Pittsburgh* Section opened the 1957–58 season with a conducted tour through the Pullman Standard Car Mfg. Co. at Butler, Pa.

Braving a terrific rainstorm, the first rainfall in over two months, 110 members and guests made the trip and were amply repaid for their time and effort, by witnessing one of the most interesting tours of plant operations ever made by the section.

After assembling at the Pullman Standard cafeteria for a most enjoyable luncheon at 12:00 noon, the attendees were briefed by H. S. Hagan, manager of the plant, on just what the tour would cover, following which, experienced personnel, including assistant plant superintendent, chief welding engineer, plant engineer, shop superintendent and others, conducted groups of ten through the plant for a closeup of operations and a description of the work and method being used.

Fabrication and welding of various types of cars, including covered and open hoppers and several different designs of gondolas, were witnessed.

Special jigs, fixtures and clamping devices for subassembly and welding were pointed out and the operations fully described from the preliminary fabrication of subassemblies to the final assembly and completion of entire cars. No effort was spared by the Pullman personnel to acquaint the members and guests with the fullest information.

Following the tour, the members returned to the company cafeteria, where a question and answer session presided over by H. S. Hagen and Section Chairman W. D. Doty answered many questions. The entire organization extended itself to see that all questions asked were answered frankly, openly and without reservation.

The members voted this one of the most interesting and satisfactory visitations ever made by the Section and were loud in their praise of Mr. Hagan and his personnel for their efforts in showing the members how cars are built.

As a climax to a wonderful afternoon, the Pullman Standard Car Manufacturing Co. presented each of the members and guests with a beautiful and practical portfolio filled with pictures and data of the Pullman Co.

WELDING PROBLEMS

Portland, Ore.—The *Portland* Section met on September 10th for a dinner meeting at the Heathman Hotel.

After a short social hour, the members sat down to a good dinner in one of the banquet rooms of the Heathman. These dinners are usually a social event, with no speaker.

3 BIG REASONS WHY SO MANY WELDERS HAVE SWITCHED TO HI-AMP® ELECTRODE HOLDERS

1- Wrap around Glass Fibre Tip Insulation—30% more heat resistant than any other make.

2- Brilliant Red Tips and Trigger-Bright Yellow Handle—all Glass Fibre, an outstanding Safety Feature.

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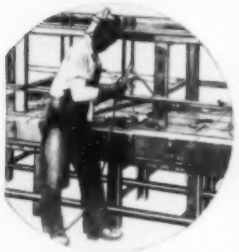

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Precision Welding can offer a savings over other methods of assembly, broaden your operation cut costs, increase profits. The ideal unit for this type work is the Challenge Precision Welding Table. It's suitable for layout work, "tack" welding and final welding operations. T-slots permit accurate positioning and holding of the work. Made of a special analysis semi-steel, designed to withstand the welding flame or arc. Guaranteed accurate to within .002". Available in three sizes.

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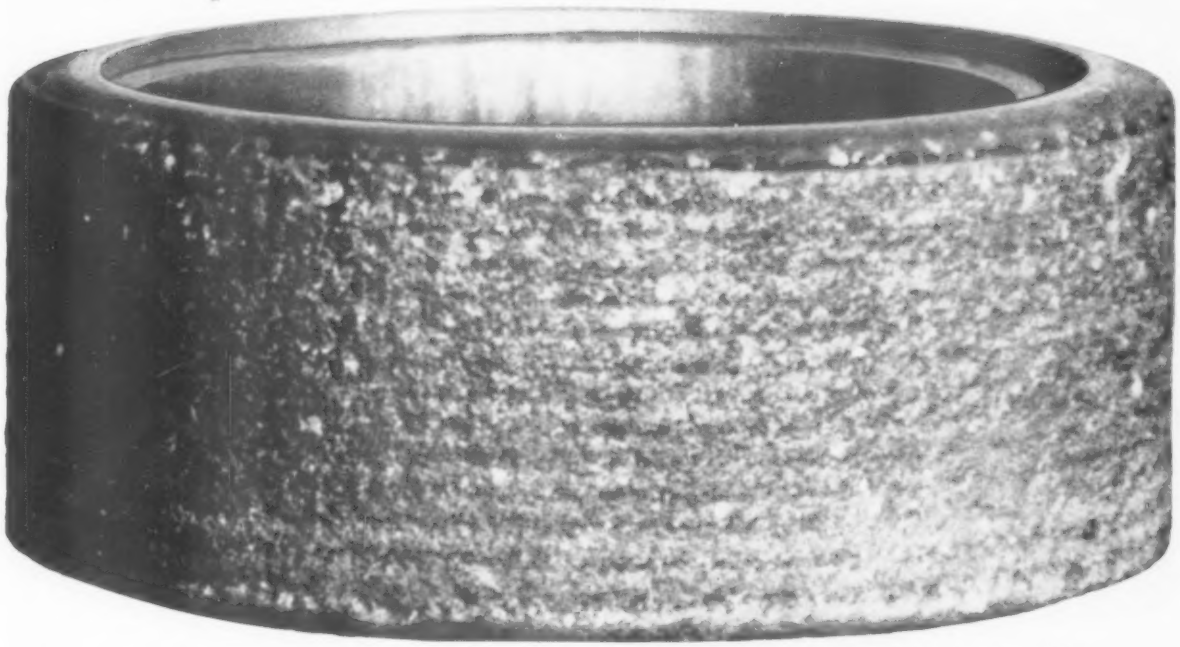
Tough and Rough!



Bulk Airco tungsten carbide bonded to a pellet mill roller by shielded arc welding form a tough, abrasive surface.

3 TIMES LONGER LIFE FOR PELLET MILL ROLLERS *with* AIRCO TUNGSTEN CARBIDE

The preparation of animal feed is extremely severe on pellet mill rollers which are subject to the highly abrasive chemical additives used in the mixture. Ordinary hardfacing materials failed to extend the service life of these rollers sufficiently to satisfy the Sprout-Waldron Company, Pennsylvania manufacturer of equipment used in the cattle and feed industry.

An Airco Technical Sales representative tackled the problem. After extensive experiments, tungsten carbide was welded to the rollers, using Air Reduction's inert gas–shielded arc process–Heliwelding. The rollers were then put into service at one of Sprout-Waldron's customer plants.

The operation was a complete success. The rollers protected by Airco tungsten carbide lasted 2 to 3½ times longer than regularly hard-faced rollers. In a production set-up using bulk Airco tungsten carbide, Sprout-Waldron has also reduced welding time by 25%. And further savings are realized because the tungsten carbide forms a hard, abrasive surface which eliminates the need for grinding welds smooth and cutting slots in the face of rollers.

Next to diamonds, tungsten carbide is the hardest commercial material known. If you have any problem concerning abrasion, call on our Technical Sales Service Dept. Let us show you how tungsten carbide—in bulk or electrode (Tungtube) form can provide resistance to abrasion in many applications.

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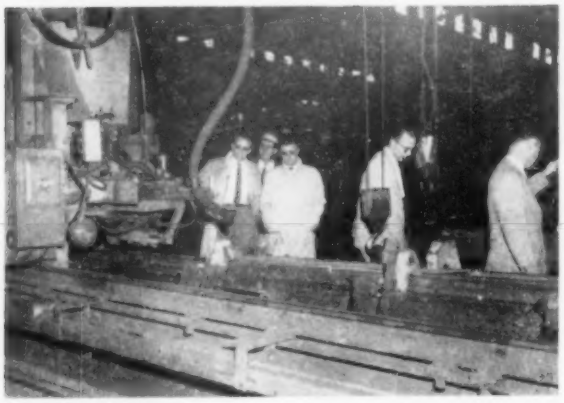
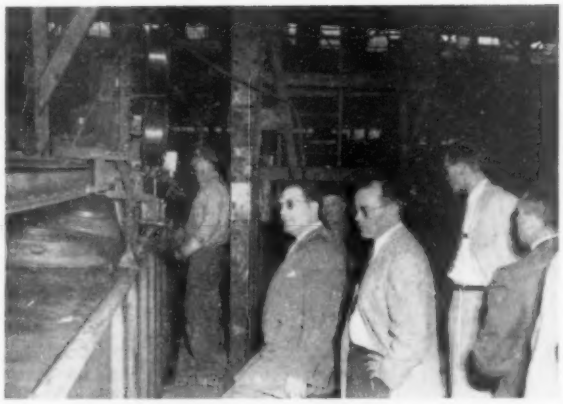
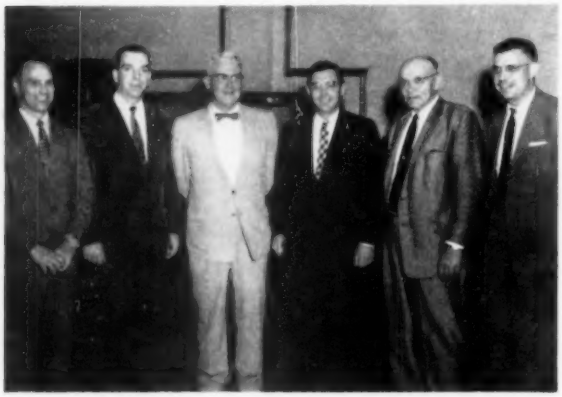
PULLMAN PLANT VISITED BY PITTSBURGH SECTION



Visitors watching the automatic seam-welding of car sill held in a clamping device



Another group shown witnessing the continuous welding of roof in closed hopper car



Representatives of the Pullman Standard Car Mfg. Co. and officers of the Pittsburgh Section who officiated at the Plant Visitation on September 20th in Butler, Pa. Reading from left: L. Warheit, H. B. Martin, and H. S. Hagan of Pullman Standard; W. D 'O. Doty, Section chairman; W. G. Boese of Pullman Standard, and H. E. Cable, Section vice-chairman

Mr. Boese, chief welding engineer, answering questions from the members and guests on return from the tour of plant operations. Dr. Doty, looking on, handled the situation in his usual efficient manner

At the conclusion of the meal, and after a brief intermission, Chairman Paul L. Buck called the meeting to order. After introduction of new members, and reports of various committees, the Scholarship Committee was called upon. Carl Love, chairman, presented Ray Smith, the student selected to receive a scholarship, of $250. Mr. Smith was presented with his scholarship check and it was moved and seconded that he also be given a student membership in the Society.

Program Chairman Orville Focht introduced the guest speaker, E. B. (Gene) LaVelle AWS. Mr. LaVelle is employed as specialist for pressure vessel and piping code, Construction Engineering Operations, General Electric Co., Richland, Wash.

Mr. LaVelle discussed the welding programs encountered at Hanford. He illustrated his talk with slides showing problems at the Atomic Energy Plant, and methods used to get the kind of welds demanded. Much of their welding is done with inert-gas-shielded tungsten-arc and metal-arc welding processes. Inasmuch as several companies represented by the members do stainless-steel work for the Hanford Plant, the fifty-one members present were very interested. This led to a spirited question and answer session.

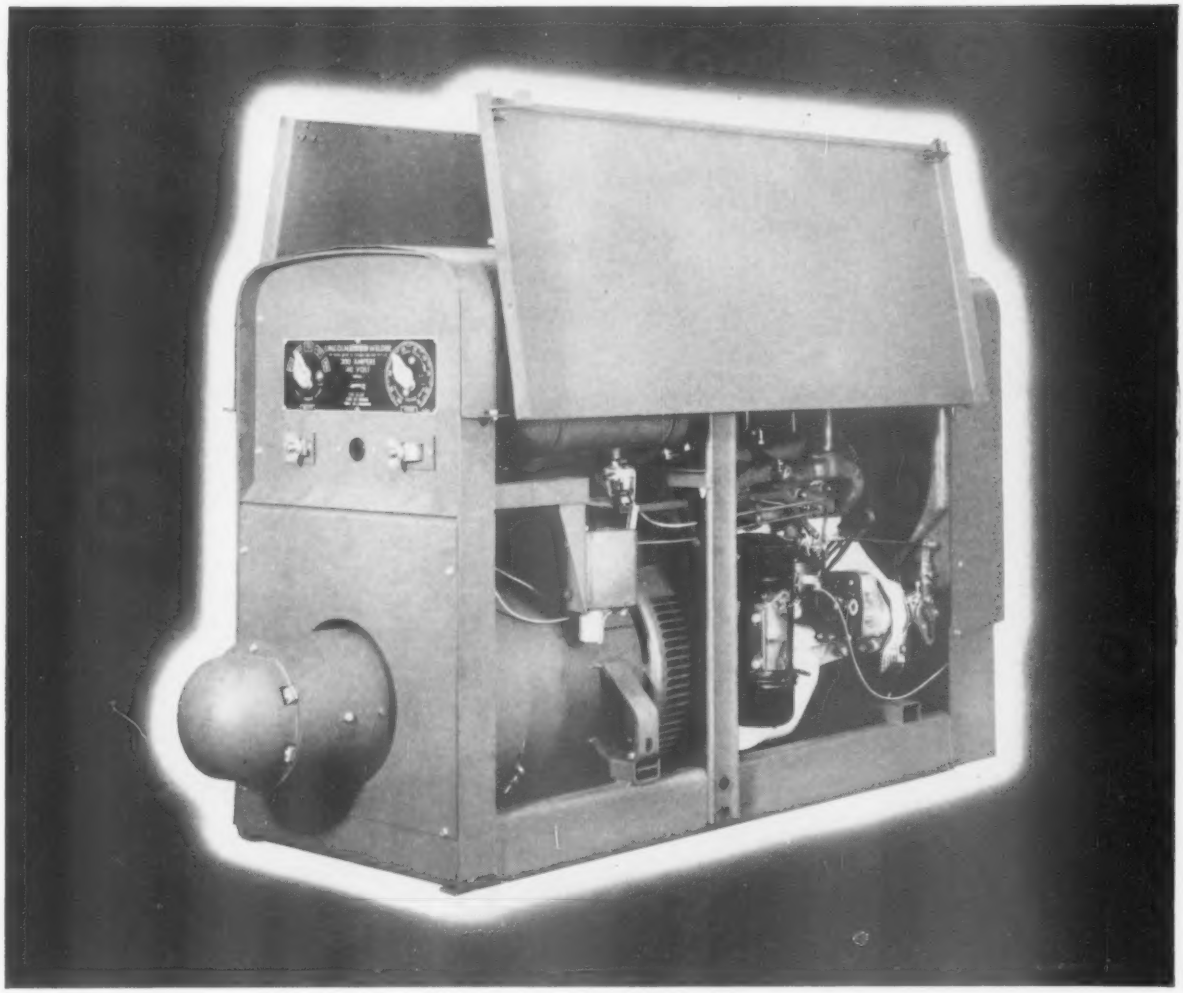
Mr. LaVelle also showed a 16-mm color and sound film entitled "Operation Ivy." This was a 28-minute film showing the weapons test series of 1953 at the AEC Pacific Proving Grounds. It covered the assembly of the fleet and technical men, the explosion preparations, instrumentation and radiation, and visual recording of what was commonly called the "Hydrogen Bomb." The power displayed is awe-inspiring.

RADIOACTIVE MATERIALS

Seattle, Wash.—The *Puget Sound* Section held a dinner meeting on September 12th at the Engineers Club, Seattle.

Speaker at the meeting was E. B. (Gene) LaVelle AWS, specialist on pressure vessel and piping codes for the General Electric Co., Hanford Atomic Products Operation at Richland, Wash. Mr. LaVelle discussed problems of welding in radioactive equipment and the problems involved in radiation. Fabrication of the massive Hanford Type reactors and a Hanford technique for inert-gas welding of stainless pipe and many other features of the work done at Hanford were covered.

The U. S. Air Force film "Operation Ivy" on the 1953 weapon test series at the AEC Specific Proving Grounds was shown.



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With all due respect to this famous machine, we are proud to announce its successor. The K-6090 has all the features of its illustrious predecessor *plus* many improvements designed for more efficient operation.

The popular F-162 Continental engine has been beefed-up to produce *more horsepower.* 36 hp (at the same low rpm) assures top output after thousands of hours of use—gives full welder performance at high altitudes.

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Shield-Arc's famous *dual control is even more precise.* Increased steps of current selection provides, exactly, the right type of arc.

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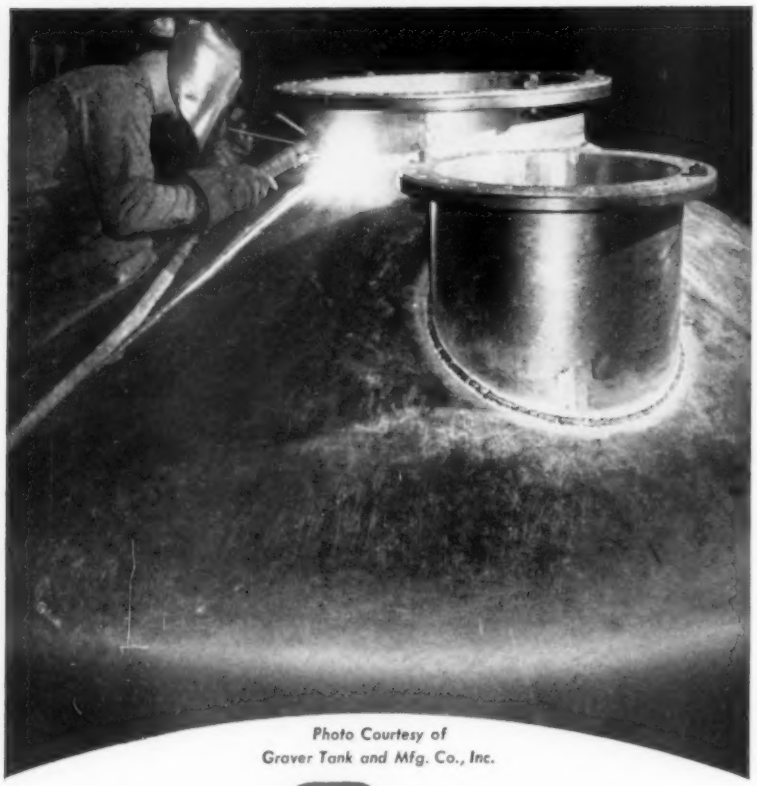

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The inert-gas-shielded-arc process made aluminum welding practical . . . but it takes Arcos quality in aluminum bare wire to assure you the most dependable results possible. Because no flux is used, the chemical analysis and cleanliness of the wire must be within exacting limits. Arcos' long experience with weld metallurgy, plus rigid controls in manufacturing, guarantee this vital factor. Arcos aluminum wire is your best assurance of stronger, more ductile, more corrosion-resistant welds.

ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

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This was the first meeting of the new fall term and sixty members and guests were in attendance.

JOINING OF ALUMINUM

Saginaw, Mich.—On Thursday, September 12th, the *Saginaw Valley* Section opened its 1957–58 meeting series with 95 members and guests in attendance.

After dinner, Don Bigler, of the Public Relations Department, United States Steel Corp., presented an illustrated discussion of the erection of the steel superstructure of Michigan's new Mackinac Bridge.

After intermission, W. M. Rogerson [AWS], of Alcoa Process Development Laboratories, presented a technical discussion on the "Joining of Aluminum and Its Alloys." The various methods of joining aluminum, such as fusion welding processes, brazing processes and resistance welding, were discussed as well as field applications and detailed joint performances.

HANGAR VISITED

San Antonio, Tex.—The *San Antonio* Section visited the "Big Hanger" at Kelly Air Force Base on Tuesday, September 24th. This building is 2000 ft long, 300 ft wide, 90 ft high, with 1,075,000 sq ft of floor space, and is said to be the largest single-span building in the world. Approximately 1800 people work in this building at one time, and it was noted that twelve planes were being worked on simultaneously. Due to the massiveness of the structure and control, the operation must be broken down into sections, divisions, departments and squads. B-52s and B-47s were seen in the various stages of reconditioning. The welding of aluminum, stainless steel and manganese was observed in the welding shop.

Dinner and refreshments were served in the Officers' Club to 73 members and guests. Fred Smith, chairman of the Program Committee, was the coffee speaker.

Col. C. A. Mixon was the speaker of the evening, using as his topic, "What the Military Means to San Antonio." He presented a short history of Kelly Air Force Base, pointing out that it is actually the maintenance headquarters for the Air Force, and noting its value to the city, both employment-wise and money-wise. Col. Mixon is comptroller for the San Antonio Air Material Area. Before receiving this assignment, he served as the chief of the Logistical Data Processing Development Office at Kelly Air Force

Base where he pioneered the installation and operation of the IBM 705 electronic data processing equipment.

NUCLEAR PUMPS

San Jose, Calif.—The *Santa Clara Valley* Section met on September 24th for dinner and meeting at the Hawaiian Gardens in San Jose. This was the first meeting of the new year.

Frank R. Drahos AWS, senior metallurgist for Byron Jackson Division, Borg-Warner Corp., Los Angeles, was the guest speaker. His subject was "Welding for Nuclear Pumping Applications." Mr. Drahos described welding procedures and problems in regard to building pumps for water and molten metal (sodium) for atomic projects. Emphasis was made of inspecting metals and weldments. Slides showed construction of pumps.

There was an interesting question and answer period in regard to specifications, as presently written, covering inspection and welding for atomic energy projects.

WELDING OF ALUMINUM

Miami, Fla.—The first regular fall meeting of the *South Florida* Section was held on September 18th in the Miami Firemen's Benevolent Association Hall.

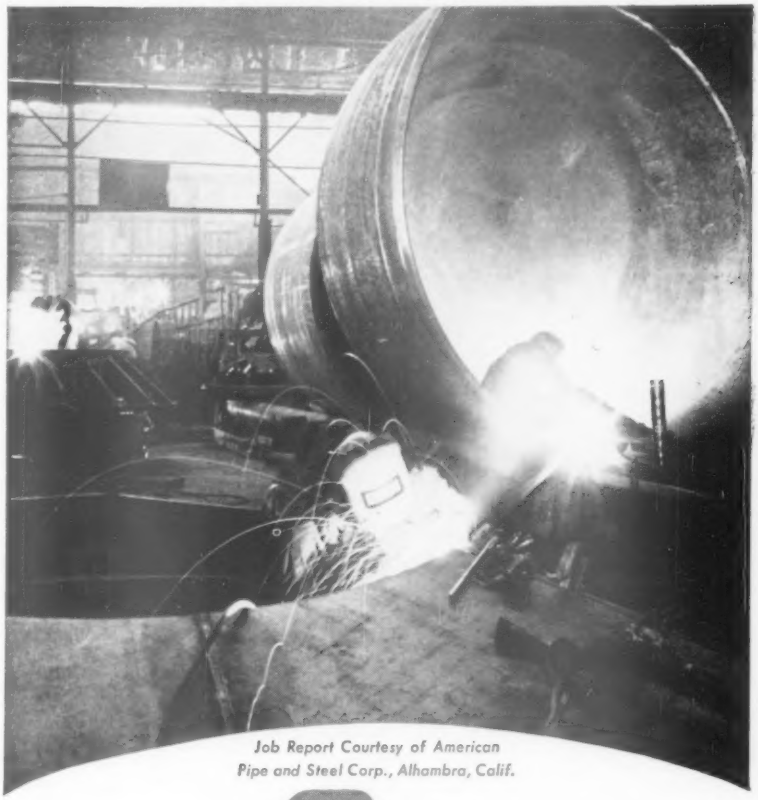
Guest speaker was J. B. West, Alcoa's southeastern development engineer, who discussed the advancement in the use of aluminum brought about by the continuing research in methods and processes involving welding. He pointed out that there are many known alloys of aluminum with highly desirable physical properties, but fabrication of these alloys is so difficult that they cannot compete pricewise with other metals of equivalent characteristics. However, as time goes on, the fabrication difficulties are being solved with new techniques permitting what appears to be the release of new and better alloys.

So as not to give the impression that aluminum and aluminum alloys are difficult to handle, Mr. West showed films of torch welding and arc welding, the latter of both tungsten-electrode and consumable-electrode types which were well received, in spite of projector troubles, as they furnished considerable fuel for the question and answer period.

SUPPORT YOUR SOCIETY

—BE ACTIVE!

When heavy chrome-moly welds must pass X-Ray Inspection



Job Report Courtesy of American Pipe and Steel Corp., Alhambra, Calif.

WELD WITH ARCOS

CHROME-MOLY ELECTRODES

In setting up this job—fabricating heavy alloy components of lead melting pots—new welding procedures were required to assure that all welds would pass x-ray inspection. With the help of Arcos Technical Service, both manual and submerged arc procedures were established and ARCOS Electrodes and Rods were used exclusively. The quality of Arcos weld metal consistently assures internally sound, flaw-free welds. And Arcos Technical Assistance prevented problems on what could have been a "tricky" job. ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

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Effective September 1, 1957

MEMBERSHIP CLASSIFICATION

A—Sustaining Member B—Member C—Associate Member

D—Student Member E—Honorary Member F—Life Member

Total National Membership

Sustaining Members	176
Members	6,141
Associate Members	6,402
Student Members	156
Honorary Members	9
Life Members	15
Total	**12,899**

Support Your Society—Be Active!

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Haggard, H. W. (C)
Odom, Gerald S. (C)
Sute, William T. (C)

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Rainis, Anthony V. (B)

CHICAGO

Robson, Charles C. (B)
Satterlee, Harry C. (C)
Shirk, Charles A. (B)
Soehrmann, Howard K. (B)

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McGarvey, William A. (B)

CLEVELAND

Baker, Edward C. (B)
Miller, Robert A. (B)
White, Trevor (B)

COLUMBUS

Mount, Roy A. (B)
Suydam, Evert P. (D)

DALLAS

Harrell, Thomas M., Jr. (C)

DETROIT

Banks, William D. (B)
Fick, Alvin H. (C)
Kennedy, Harry (B)
Pelkey, Harold (C)

HARTFORD

Case, Glendon H. (B)
Kollman, Kenneth G. (C)

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Cooper, Garney Lee (B)
Cooper, Lois (B)
Funderburk, Horace B. (C)
Gresham, Paul J. (C)
Pennington, W. E. (B)
Price, Lee H. (B)
Stuebner, V. A. (C)
Ward, Robert T. (C)

IOWA

Rinehart, Max (B)
Roush, Henry E. (C)

IOWA-ILLINOIS

Crelly, Jack W. (C)
Meyer, Fred G. (C)

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Roberts, Joseph A. (B)
Throckmorton, Melvin R. (B)

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Eby, Wilbur E. (B)
Stick, Clarence T. (B)

LONG BEACH

Green, William E. (B)

LONG ISLAND

Cahill, Thomas J. (B)

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Dukes, Robert E. (B)
Eldred, George W. (B)
Grantham, Jack (D)
Johnson, Oscar G. (B)
Lewis, Clarence E. (C)
Loucks, Walter G. (B)
Lynch, Edward C. (B)
Valentine, Joel L. (B)

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O'Toole, William G. (C)
Similey, Shelby G. (C)

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Cox, John (B)
Fisher, Jack A. (B)

MARYLAND

Stavar, John P. (B)

MILWAUKEE

Kelly, L. M. (C)
Murock, Harold (C)

NEW HAMPSHIRE

Browning, James A. (B)

NEW JERSEY

Bodine, F. O. (B)
Dyer, William J. (C)
Fannon, Robert (C)
Fisher, William J. (C)
Geideman, William A., Jr. (C)
Halsey, Robert A. (B)
Kinch, John F. (C)
Reitz, Donald S. (C)
Williams, George (C)
Wroth, Robert Stewart (B)

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Blanchard, James U. (C)

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Mounce, William S. (B)
Pogue, William A. (C)
Theiler, Werner C. (C)

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NORTHEAST TENNESSEE

Bailey, L. F. (B)
Gerloff, J. G. (C)
Roseberry, Roy B., Sr. (B)
Stepp, Robert (B)
Strother, John P. (B)

NORTHERN NEW YORK

Johnson, Edward D. (B)

NORTHWEST

Alrick, Donald L. (C)

OLEAN-BRADFORD

Cooper, William E. (B)
Knight, Edward W. (C)
Stern, Peter (B)

PEORIA

Smith, William G. (C)

PHILADELPHIA

Alexander, Peter X. (C)
Beyer, Robert George (C)
Colt, Henry F., Jr. (C)
Julicher, Arthur J. (C)
Luce, Sidney L. (C)
Mangan, Charles H. (C)

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Merker, Charles G. (C)
Sanstead, Kenneth A. (B)
Wright, William D. (B)

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Williams, Joseph J. (B)

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Iverson, Einar (C to B)
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Davis, Robert E. (C to B)
Middlehurst, D. J. (C to B)
Rash, W. C. (C to B)

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Stout, Robert D. (C to B)

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Schultz, William C. (C to B)

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Bott, Harry B. (C to B)

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Russ, James J. (C to B)

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RICHMOND

Cervarich, F. R. (C to B)
Wood, L. M. (C to B)

ROCHESTER

Minckler, G. Mark (C to B)
Waldvogel, Robert K. (C to B)

SAN FRANCISCO

Tinnes, Leroy (C to B)

STARK CENTRAL

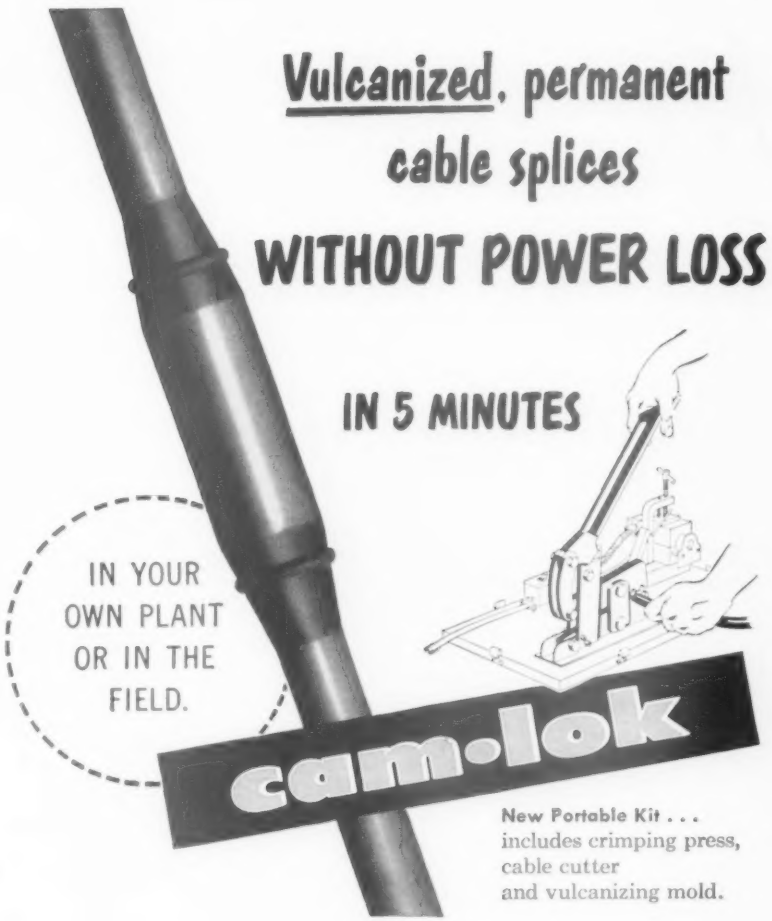
Brainard, Clifford C. (C to B)

WORCESTER

Murray, Clifford H. (C to B)

YORK-CENTRAL PA.

Reid, H. F., Jr. (C to B)



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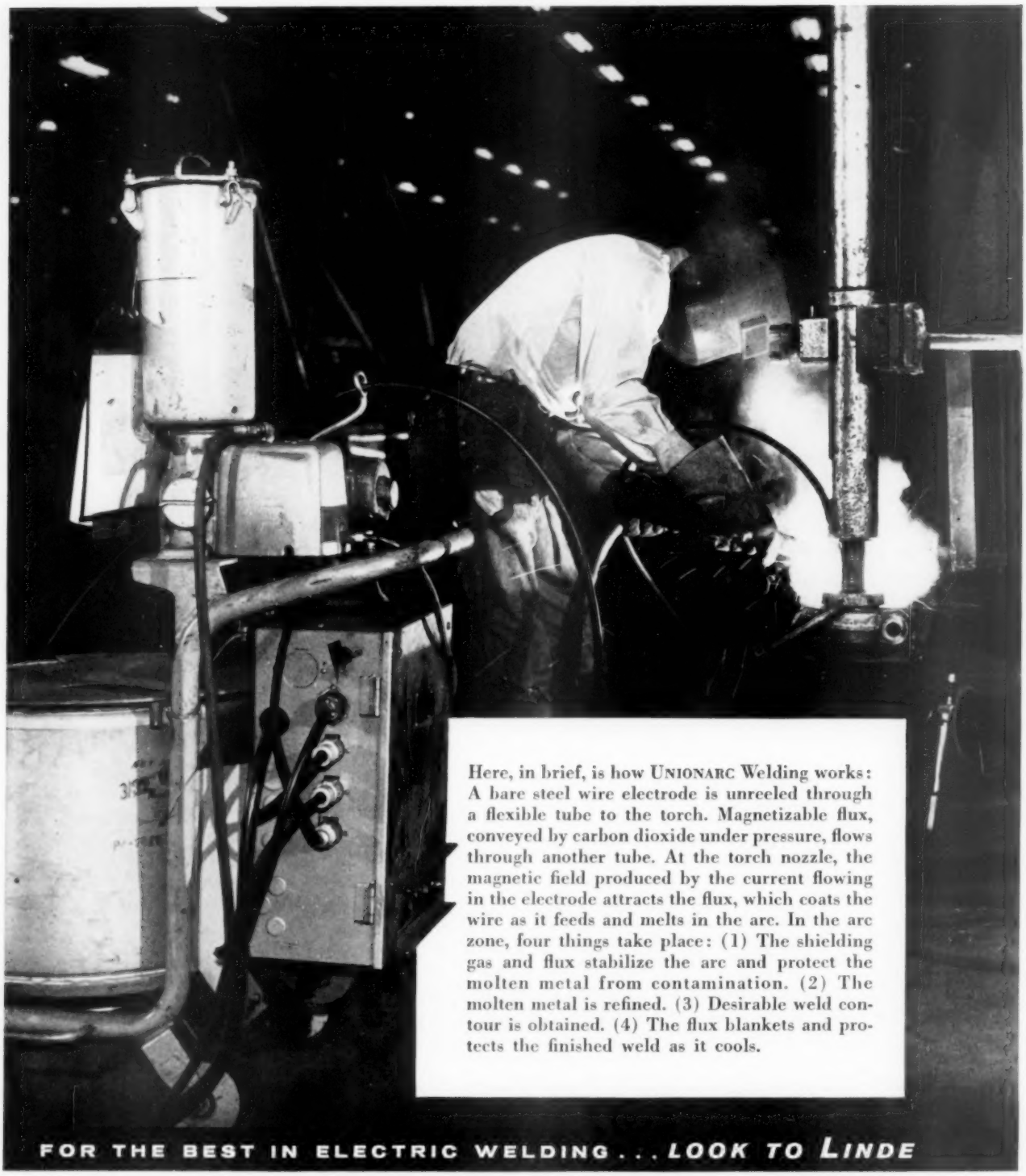

Here, in brief, is how UNIONARC Welding works: A bare steel wire electrode is unreeled through a flexible tube to the torch. Magnetizable flux, conveyed by carbon dioxide under pressure, flows through another tube. At the torch nozzle, the magnetic field produced by the current flowing in the electrode attracts the flux, which coats the wire as it feeds and melts in the arc. In the arc zone, four things take place: (1) The shielding gas and flux stabilize the arc and protect the molten metal from contamination. (2) The molten metal is refined. (3) Desirable weld contour is obtained. (4) The flux blankets and protects the finished weld as it cools.

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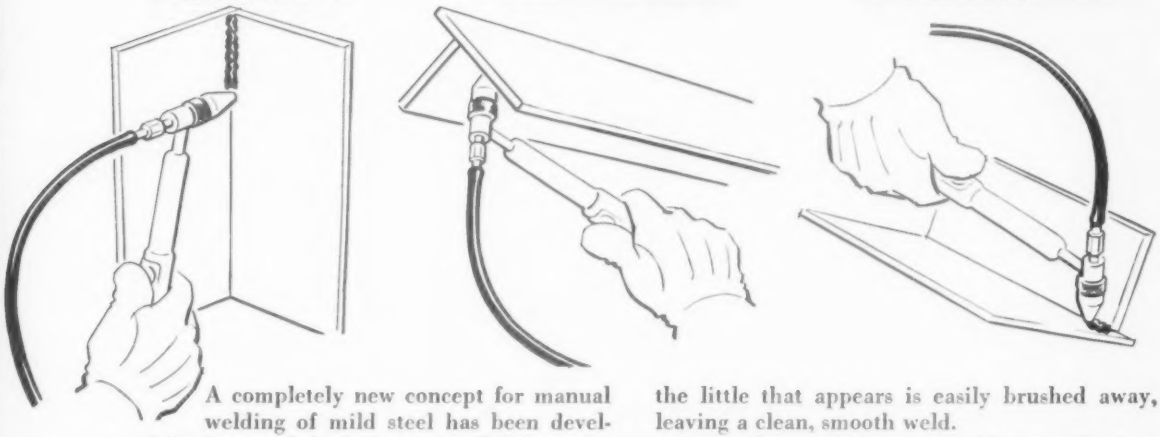
modern welding method– Flux Gas Shielded Arc Welding

UNIONARC *is an entirely new method of welding steel in all manual positions...*

VERTICAL **OVERHEAD** **DOWNHAND**



A completely new concept for manual welding of mild steel has been developed by LINDE. Called UNIONARC Welding, the method uses a continuously-fed bare steel wire electrode, which is magnetically coated with flux and shielded by carbon dioxide. The torch can be easily handled in all welding positions—vertical, overhead, downhand. Manual welds can be made at higher speeds and at lower cost than with covered electrodes. UNIONARC Welding produces high-quality welds in steel, even when moderate amounts of rust, scale, and moisture are present.

Among the numerous advantages of UNIONARC Welding are these: Rate of operation is up to three times faster than with covered electrodes. There is no stopping to renew electrodes, since a single loading of wire can be fed smoothly and continuously for periods up to a week. Manual skill needed is no more than that required with covered electrodes. In vertical and overhead positions, the deposition rate in UNIONARC Welding is two to three times greater than with covered electrode methods; in downhand positions, up to twice as great. There is practically no spatter—the little that appears is easily brushed away, leaving a clean, smooth weld.

LINDE has made many notable contributions to welding. Among these are the introduction and development of submerged arc welding (UNIONMELT Welding), non-consumable electrode, inert gas shielded arc welding (HELIARC Welding), and the development of Sigma (shielded inert gas metal arc) welding. LINDE's newest method, UNIONARC Welding, is another *first*—a truly important contribution. Its simplicity and versatility make it unique. Its efficiency and economy have been proved in actual production work. Write *now* for details about UNIONARC Welding, or call the LINDE office nearest you.

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For copies of articles, write to periodicals in which they appear. A list of addresses is available on request

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed Copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D. C.

2,790,065—Control Means—Kingsley A. Doutt, Cortland, Ohio, assignor to Federal Machine and Welder Co., Warren, Ohio, a corporation of Ohio.

The patented control means relate to a flash welder having a movable platen. The control includes means for causing movement of the platen in a welding direction at a certain given pressure, and other means for causing movement of the platen in a welding direction at a higher pressure. A further member is provided for interrupting the action of the first mentioned means after the second mentioned means is causing movement of the platen.

2,790,066—Stud Welder—Clyde H. Haynes and Lorenz John Mowry, Elyria, Ohio, assignors to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

A novel stud welding device including a stud welding gun body, a chuck, and a tubular shield surrounding the chuck is disclosed in this patent. A ferrule holder is slidably positioned in the shield for supporting a ferrule in welding position. This holder has conduit means therein connecting to a gas inlet in the said shield for conducting gas from the inlet to the vicinity of the ferrule and within the shield. The holder and the shield cooperatively define a gas valve.

2,790,067—Apparatus for Hot Upsetting—Joseph J. Riley and Forbes A. Hurcomb, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

This patent particularly relates to current flow control means for apparatus for hot upsetting a metal workpiece and wherein a pair of electrodes are provided and movable means are present for applying pressure to the workpiece to deform it.

2,790,656—Aluminum-Dissimilar Metal Joint and Method of Making Same—Lloyd A. Cook, Opportunity, Wash., assignor to Kaiser Aluminum & Chemical Corp., Oakland, Calif., a corporation of Delaware.

Cook's patent relates to a method of making a joint between an aluminum member and a member of metal dissimilar to aluminum and which is normally incapable of being fusion bonded to aluminum. The method comprises providing the dissimilar metal member with a facing of buffer metal thereon in the area to be bonded, and inert-gas arc welding the buffer metal facing to the aluminum member by forming an aluminous metal weld therebetween. The novel metal joint so produced is also covered in this patent.

2,790,891—Welded Joints and Method of Making the Same—James William Welsh, Summit, N. J., assignor to Signal-Stat Corp., Brooklyn, N. Y., a corporation of New York.

Welsh's patent is on a method of weld uniting a high carbon spring steel member to a mild steel member and includes the steps of superimposing such members and forming a first spot weld therebetween to provide a high air hardening in the weld heat-affected area of the high carbon steel member. Next a piece of metal from the group consisting of Nickel, Platinum and alloys thereof is placed against the spring steel member and is spot welded to such members by a second spot weld immediately adjacent and in the heat-affected area of the first spot weld to change the metallurgical characteristics of the weld heat-affected area to those of a non-air hardening alloy of the spring steel member and of the attached metal piece.

2,790,892—Resistance Welding Machine—Arthur Colon, Forest, Belgium.

Colon's patent relates to a resistance butt welding machine and which has a jaw for one of the pieces to be welded, and a movable jaw for a second piece to be welded to the first one. The patent relates to particular control means for controlling movement of the movable jaw.

2,790,925—Combined Electrode Feed Conduit and Driving Means Therefor—George G. Landis, South Euclid, and Harold S. Payne, Cleveland Heights, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

This patent relates to arc-welding apparatus wherein a welding head is provided. An electrode source is provided remote from the welding head, and a flexible conduit connects the electrode source to the welding head for passage of an electrode therethrough. Electrode drive means are provided adjacent the electrode source for advancing the electrode into the conduit, and electrode drive means are provided adjacent the welding head for pulling the electrode from the conduit. A single power means connects to each drive means for actuating them simultaneously.

2,791,667—Automatic Brazing Apparatus and Method—Earl J. Clark, Marblehead, and Henry T. Libby, Reading, Mass., assignors to General Electric Co., a corporation of New York.

The patented apparatus is for brazing armature winding leads to risers of commutator segments after the leads have been placed in slots in the risers together with a brazing alloy metal. A U-shaped induction coil is provided and is adapted to be placed adjacent one of the risers to induce currents therein sufficient to heat such riser to a temperature which will melt the metal therein. Other means are provided for sensing such temperature in the riser. A further member is connected to the sensing means to rotate the armature assembly to move the heated riser from under the coil and to move a riser next adjacent to such heated riser under the coil.

2,791,673—Process and Device for Electric Arc Welding in a Protective Atmosphere—Robert Arnaud, Boulogne-sur-Seine, France, assignor to L'Air Liquide, Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude, Paris, France.

This welding method in an atmosphere of protective gas is characterized by the fact that it utilizes two welding arcs in series in the same feed circuit. The welding arcs extend respectively between the part to be welded and a non-fusible electrode, and between the part and an electrode of the fusible metal to be deposited on the other hand. The two electrodes are sufficiently close to one another that only a single weld pool is formed on the part to be welded.

2,792,490—Welding Method and Consumable Weld Insert Therefor—Theodore A. Risch, New London, and Herbert B. King, Niantic, Conn., assignors to General Dynamics Corp., New York, N. Y., a corporation of Delaware.

This welding process is for butt welding the adjacent edges of two metal parts together without the use of any backing device. The welding method comprises the steps of abutting the edges of the tubular members to be welded together against a consumable insert piece and moving a welding torch along one side of the insert and supplying sufficient heat through the torch to melt the insert completely and form successive molten weld puddles as the torch is advanced. The consumable insert is so proportioned and made that the heat melts the consumable insert and the parent metal of the parts being welded together where they abut the insert to form the successive molten weld puddles containing both insert and parent metal combined in the puddles. The forces of surface tension, adhesion and cohesion are permitted to act upon the molten weld puddles to form, upon solidification, a homogeneous weld free from cracks and crevices and having a substantially smooth-surface bead on the side of the welded parts opposite the side of the heat input.

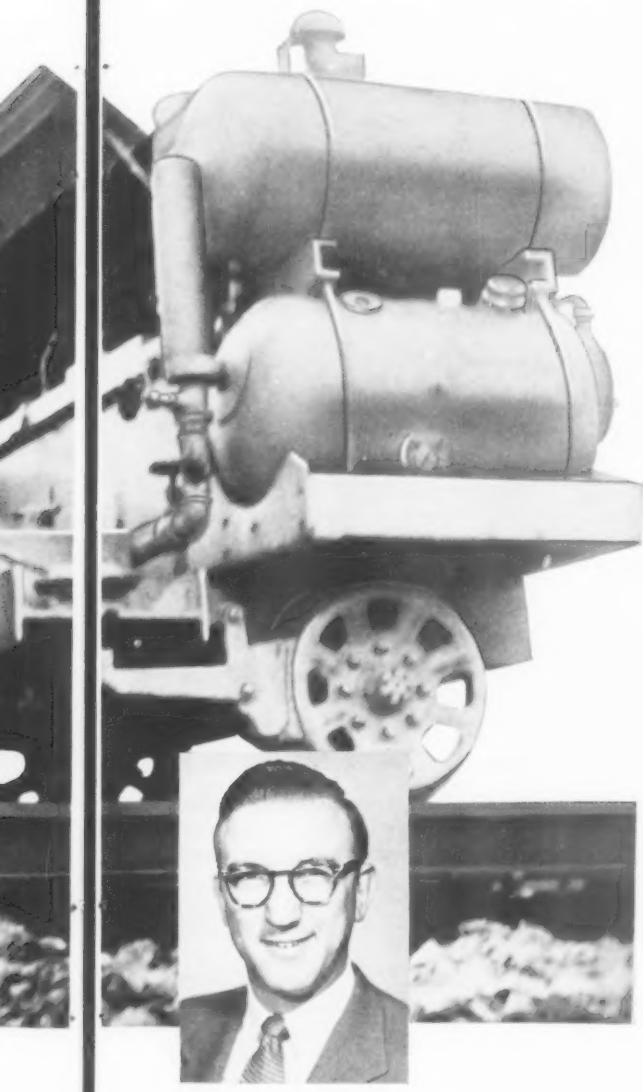
You can't drive spikes

SpikeMaster uses pneumatic power to drive four spikes at a time. Welds must withstand machine-gun bursts of impact. SW-44 electrodes make it seem easy.

SpikeMaster shown with one set of driving guns operating . . . the other in travel position. Both sets operate simultaneously when desired. The self-propelled unit has hydraulic powered turntable . . . removes itself from track. All critical welds are made with A. O. Smith SW-44 iron powder electrodes.

For more details, circle No. 22 on Reader Information Card

with a tack-hammer!



RMC SpikeMaster has driving power built-in; welds made with A. O. SMITH SW-44 electrodes provide guts for working on the Railroad

First, you nip the railway tie up firmly against the rails. Then you drive four spikes—one on either side of both rails. All at a rate of better than 4 or more ties per minute. It's quick and *easy* — with Railway Maintenance Corporation's SpikeMaster.

EASY . . . because these fast-working units are built to deliver sure spike-driving power without faltering in tough mainline service.

Like all RMC railroad maintenance equipment SpikeMaster features welds made with A. O. Smith SW-44 electrodes on heavy-gauge steel components.

An iron powder electrode (AWS class E-6024), the SW-44 excels in high-speed operation . . . deposits far more tough weld-metal than conventional rods. Actually, many users report the SW-44 cuts welding time 25% . . . electrode cost by as much as 10%. Speed and strength are far from all. You get smooth, self-cleaning welds . . . the quality look that sells your product.

Want more facts about the SW-44 and other top-performing electrodes? Call "Your man from A. O. Smith" . . . or write direct.

The man from A. O. Smith

Byron Motl is the A. O. Smith welding consultant who worked with Railway Maintenance Corporation. More than a salesman, he's a trained welding specialist . . . ready and eager to help with production problems.

Through research A.O. Smith *. . . a better way*

A.O.Smith

CORPORATION

WELDING PRODUCTS DIVISION

Milwaukee 1, Wisconsin

A. O. Smith INTERNATIONAL S. A., Milwaukee 1, Wisconsin, U. S. A.

For more details, circle No. 22 on Reader Information Card

NEWS of The Industry

Airco Acquires Welding Firm

Arcrods Corporation, a leading producer of arc welding electrodes with plants in Cleveland, Ohio and Sparrows Point, Maryland, has become a wholly-owned subsidiary of Air Reduction Co., Incorporated, it was announced by John A. Hill, Airco's president. William Brainard, president of Arcrods, will continue in that capacity. Arcrods has been furnishing electrodes to Air Reduction and Air Reduction has had a stock interest in Arcrods.

Welding Subject of Foundry Award

The Steel Founders' Society of America recently announced that Joe Jopling, project engineer of Phil H. Edwards Construction Engineers, Fort Worth, Tex., has been awarded $1000 in addition to a "national gold certificate" in recognition for his winning paper during SFSA's 3rd Product Development Contest. Mr. Jopling's entry, "Composite Weld Construction for Rock Ripper Frame," was adjudged at the SFSA's 55th Annual Fall Meeting at The Homestead Hotel, Hot Springs, Va.

ASCE Elects Officers

The American Society of Civil Engineers has elected Louis R. Howson, of Chicago, president for one year. Mr. Howson, succeeding Mason G. Lockwood, of Houston, Tex., was installed October 16th at the annual meeting of the Society in New York City.

The vice-presidents-elect are Waldo G. Bowman and Samuel B. Morris. They will serve two years.

The new directors, elected for three years, are Prof. Weston S. Evans, Craig P. Hazelet, Donald H. Mattern, John E. Rinne, Philip C. Rutledge and Tilton E. Shelburne.

Linde Appoints Distributor

Hill Equipment Co., of St. Louis, Mo., has been appointed a distributor for the Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y. The new distributor will handle a complete line of welding equipment and supplies, and will operate out of Granite City, Ill.

Awards at College Level

Engineering undergraduates in twenty-six engineering schools and universities received recognition and awards this year in the annual competition sponsored by The James F. Lincoln Arc Welding Foundation of Cleveland for student designs of welded machines and structures. A total of forty-six awards amounting to $5000 were given to engineering undergraduates. Duplicate awards in scholarship funds were presented to schools honoring the students whose designs received the main awards. Awards were made for papers submitted to The Lincoln Foundation presenting designs of machines and structures improved through the use of welded design.

The First Grand Award of $1250 went to a husband and wife engineering team, Charles and Ann Hutchins, who, as undergraduates at the University of Michigan, collaborated to submit an entry on the design of various parts used in a welded two-stage press. Their departments were each given $500 in scholarship funds honoring their achievement. In the ten-year history of The Lincoln Foundation competition, this is the first year a woman has received recognition among the generally predominate male engineering undergraduates.

Another team received the $1000 Second Award. Eugene A. Jahnke of Charles City, Iowa, and Keith Wilson of Monroe, Wis., both enrolled in the Department of Architectural Engineering at Iowa State College, designed a welded rigid steel frame to be used in an elementary school building. Their department received in their honor scholarship funds of $500.

The Third Award went to Donald Malcolm of Pittsburgh who, as a student in the Machine Design Department of Cornell University, designed a machine for handling work for automatic welding. He received $500 and his department was given $250 to award in scholarships.

The Lincoln Foundation is sponsoring a similar competition for the current school year again to interest undergraduate engineers in studying how welded design can reduce costs and improve both machines and structures of all types. Any resident undergraduate can participate.

Welded Ring Manufacturers

Announcement has been made of the formation of The Welded Ring Manufacturers' Association. This association has been organized to fulfill better the requests of code and specification writing bodies for industry-wide acceptance of new and improved specifications for rings and to assist in the formulation of such specifications. The association has appointed the following committees: a Technical Committee, a Committee on Procurement; and, a third committee on Industry Statistics.

The WRMA's member companies are: The American Welding & Manufacturing Co.; The Cleveland Welding Division, American Machine & Foundry Co.; Cooper Alloy Corp.; Dresser Manufacturing Division, Dresser Industries, Inc.; Edgewater Steel Co.; King Fifth Wheel Co.; and Ladish Co.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1958 Spring Meeting and Welding Show:

April 14–18, Statler Hotel, St. Louis, Mo.

IAA

March 19–21. Fifty-eighth Annual Convention, Bellevue Stratford Hotel, Philadelphia, Pa.

NWSA

Southeastern Zone Meeting:

December 2–3, 1957, Atlanta Biltmore, Atlanta, Ga.

Southwestern Zone Meeting:

December 5–6, 1957, The St. Anthony, San Antonio, Texas.

To prepare new crushers for a hard life, Wasco County, Oregon, hardfaces rollers with Victor alloy rod. The rollers showed no discernible wear after crushing 3100 tons of extremely hard and abrasive basalt.

Lifesaver for new or used equipment **VICTOR Hardfacing Alloys**

Wasco County, Oregon, uses lots of crushed basalt. This rock crushes readily, yet is extremely hard and highly abrasive, consequently tough on rollers. So, as standard practice, Supt. Wayne Weeks hardfaces all rollers in brand new crushers, before ever they crush a single basalt rock. He reports hardfacing of new equipment prevents excessive wear of surface material, thus maintaining roller size during the work hardening period.

On this new crusher, he used 200 lbs. of Victor #0 semi-automatic wire, size 7/64", to hardface roller faces, and 50 lbs. of tube Victorite coated for finish work around the roller edges. Longer crushing life will quickly pay for the rod.

You, too, can save money and extend the life of equipment subjected to abrasion, impact and heat. Simply make it standard practice to hardface both new and worn equipment with Victor alloy rods. Complete line of 27 different hardfacing rods assures you a right rod for every hardfacing need. Full range of sizes for both acetylene and electric AC and DC applications, either hand, automatic or semi-automatic. Order a supply from your Victor dealer TODAY.

FREE Victor Hardfacing Manual shows you right rod to use and how to apply it. Write us NOW for your copy.

VICTOR for welding

Profitable dealerships open; inquire now!

VICTOR EQUIPMENT COMPANY 42

ALLOY ROD AND METAL DIVISION

13808 E. Imperial Highway, Norwalk, Calif. • Wakita, Oklahoma

For more details circle No. 23 on Reader Information Card

Airco Names Wallace

H. C. Wallace, assistant regional sales manager of the Southern Region of Air Reduction Sales Co., has been appointed regional sales manager of that region, succeeding M. G. Wicker who has resigned. Mr. Wallace will maintain his office at Houston, Tex.

Mr. Wallace began his association with Air Reduction in 1929 at the Louisville, Ky. office, and has progressed through various sales positions over the years. His previous headquarters were in Louisville, Ky.

A. W. Gilpin, assistant sales manager at Houston, has been appointed assistant to the regional sales manager. R. Pringle, salesman, succeeds Mr. Gilpin as assistant sales manager.

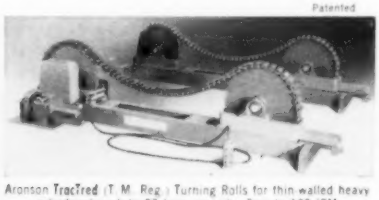
Air Products Expands in England

A new company named Air Products, Ltd., has been organized by Air Products, Inc., of Allentown, Pa., and the Butterley Company of London, England.

This new organization will be an overseas counterpart of Air Products, Inc., primarily involved in the design, manufacture, installation and operation of oxygen plants and other low-temperature equipment for the British Commonwealth and European markets. The Company will also produce and sell industrial gases, sewage treatment equipment and textile cleaning equipment.

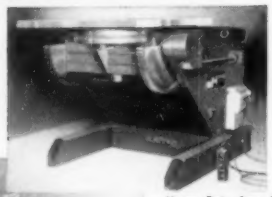
Aronson

Offers You Over 200 PROVEN Standard Stock Models of Quality POSITIONERS "POSITIONEERED" to your exact Requirements



Patented

Aronson TracTred (T. M. Reg.) Turning Rolls for thin-walled heavy cylindrical work to 27 tons capacity. Zero to 100 IPM turning speed and Built-In Grounding.

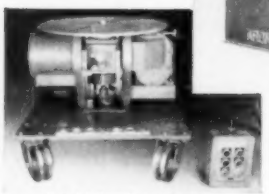


Heavy Duty Precision Built Rubber and Steel Tired Turning and Pipe Rolls, 100% overload protected. Capacities to 300 Tons.

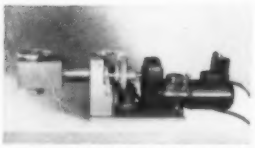
Heavy Duty Gear Driven Positioners, with Magnetic Braking, Mercury Grounding, and Optional Speeds. Capacities to 120,000 lbs.

Fully Automatic Gear Driven Positioners, featuring Geared Elevation, 135° Tilting and Variable or Constant Speed Rotation. Capacities to 120,000 lbs.

Heavy Duty Floor Turntables with precision speed control and Magnetic Braking, used for welding, burning, X-raying, etc. Capacities to 120,000 lbs., various heights and speeds.



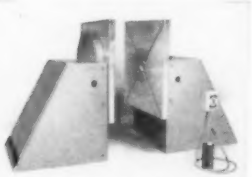
Model D Gear Driven Positioners. Compact, Precise, Rugged. Capacities to 1000 lbs.



Bench Turntable Automatic Positioners with Mercury Grounding. Capacities to 500 lbs.

Patented

Aronson Universal Balance Positioners (T. M. Reg.) position your weldments effectively, instantly for downhand welding. Capacities to 2000 lbs.



Rugged Head and Tail Stock for positioning bulky weldments between centers. Table Backup for Zero Deflection. Magnetic Braking. Capacities to 160,000 lbs.

Aronson Twinner Permanent Magnetic Clamps, six models with thousands of uses in welding set-up work. Write for bulletin.

Write for detailed engineering data

Quality POSITIONERS by Aronson MACHINE COMPANY
ARCADE, NEW YORK

For more details, circle No. 24 on Reader Information Card

PLAN NOW
TO ATTEND
1958 SPRING MEETING

Lincoln Assigns Representatives

A. Lincoln Clifford, John R. Deobald and Daniel E. Doudna have joined the Lincoln Electric Co.'s district offices at Columbus, Ohio; Cleveland, Ohio; and Chicago, Ill., respectively. All three of these men were in the company's training program in Cleveland, prior to their current assignments.

Mr. Clifford, a native of Idaho Falls, Idaho, is a graduate of Weber College with a degree in Business Administration. He also holds a degree of Bachelor of Science, Industrial Management, from Utah State College.

Mr. Deobald, originally from Peoria, Ill., joined the company after receiving a degree in Mechanical Engineering from Purdue University in 1954 and serving two years as an officer in the United States Army.

Mr. Doudna, formerly of Jackson, Mich., received a Bachelor of Science, Mechanical Engineering, degree from the University of Michigan in June, 1956. He has also served with the Army.

Merger Executed by Mallory

Announcement was made on September 3rd of the integration of P. R. Mallory Co. Inc., Sharon Steel Corp., and National Distillers and Chemical Corp. to form a single company with assets exceeding $55 million. The new firm will be known as Mallory-Sharon Metals Corp. and will engage in the production of titanium, zirconium and other light metals.

Tube Turns to Expand

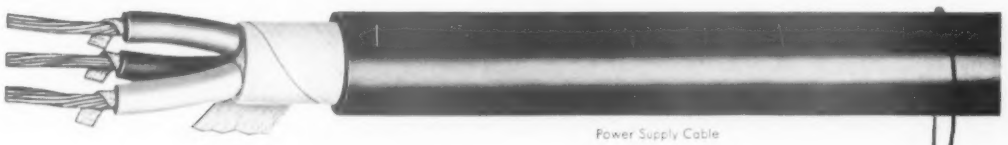
The Tube Turns Division of National Cylinder Gas Co. will increase its manufacturing area approximately 40% by converting buildings on property adjacent to its main plant.

The company announced today the signing of a $400,000 construction contract with Sullivan & Cozart of Louisville to connect three existing buildings, creating a new manufacturing area under one roof.

John G. Seiler, Tube Turns' president, said the construction program would provide plant facilities for products now in the design and development stage and for expansion of the welding fittings and custom forgings departments.

Seiler said that the program marks

If it's worth engineers' time...



...it's worth engineered cable

Belden
WIREMAKER FOR INDUSTRY
SINCE 1902
CHICAGO

4-W

Magnet Wire • Lead and Fixture Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires
Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable

For more details, circle No. 25 on Reader Information Card

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WELDING ALLOYS

Sales • Service • Research

is only as far away as a phone call or letter to any of the following warehouse-service centers:

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When you need a Eutectic District Engineer for on-the-spot assistance, you'll get immediate action by any of these centers.

EUTECTIC WELDING ALLOYS CORP.
40-40 172nd Street, Flushing 58, New York, N.Y.

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Tube Turns' greatest physical growth since it moved into its present main plant in 1938.

Hobart School to Expand

The Hobart Trade School, an educational institute sponsored by Hobart Brothers Co., Troy, Ohio, is building a new technical school in an attempt to meet the urgent need for welding technicians. To bridge the growing gap between the engineer and the welder—

this is the aim of Hobart Brothers new school.

The new Hobart Technical Institute is an outgrowth of the Hobart Trade School, a school which has graduated 20,000 welders since 1930. The need for a new technical center demanded that it be operated on a much higher level, with the ultimate goal of a full two-year curriculum leading to the certificate of Welding Associate. Metallurgy, mathematics, physics, chemistry, design and a thorough study of welding and all its aspects—these are the basic principles upon which the program will evolve. The building itself (80,000 sq ft) will house adequate classrooms for a large student body, laboratories, an auditorium, a research department, a library and complete administrative facilities.

Welding Awards for Farmers

Gary Neuschafer of Hope, Kan., received the top honors and awards this year from The James F. Lincoln Arc Welding Foundation of Cleveland, Ohio, in its annual, national arc-welding competition for high school students on farms or ranches. He received the $600 First Award for his entry describing his high-school farm-mechanics welded-shop project, a wagon chassis. In his honor, his school also received $600 for use in the shop course and his teacher, William Reynolds, received a bronze medal and citation.

The $400 Second Award went to Leemer Gene Cernohlavek of Weston, Neb. Third Awards of $200 were given to Larry Dickinson of Doyle, Calif., and Tom Schultz of Davenport, Wash. Their schools received duplicate awards and their teachers, F. W. Fox and John Elliot, were cited with bronze medals.

The Lincoln Foundation is sponsoring a similar competition for the current school year for which any high-school student living or working on a farm or ranch is eligible. Information can be obtained from the Foundation, Cleveland 17, Ohio.

Canadian Section of CGA Elects

David W. Black of The British Oxygen Canada Ltd. was elected chairman of the Canadian Section, Compressed Gas Association, Inc., at the section's annual meeting held September 9–11 at the Seigniory Club, Montebello, Que. Other officers elected were Keith W. Shaw, Imperial Oxygen Ltd., 1st vice-chairman, and W. A. Taylor, Canadian Industries Ltd., 2nd vice-chairman.

Ampco Appoints Distributor

The Columbus Welding Supply Co., 1236 Midway Drive, Columbus, Ga. has been named a stocking distributor of the complete line of Ampco Bronze Weldrod products, according to a recent announcement by Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

The new distributor, an affiliate of Keenan Welding Supplies, Inc., Albany, Ga., will handle Ampco-Trode, Ampco-Trode "AC" and Phos-Trode electrodes, filler rod and spooled wire in addition to Ampco-Braz gas-welding and brazing rods.

ELEVATED WATER TANK

A 1,000,000-gal elevated steel water storage tank was built by the Chicago Bridge & Iron Co. for the Southeastern Oakland County Water Authority at Berkley, Mich. The spheroidal portion of the structure is 87½ ft in diam with a range in head of 25 ft between the low and high water level, making the over-all height of the structure 101 ft.

For more details, circle No. 26 on Reader Information Card——→

Plant, Research Laboratories and World Headquarters

BETTER ORIGINAL FASTER
Low Temperature EUTECTIC WELDING ALLOYS
STRONGER WELDS

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS CORPORATION, 40-40 172 STREET, FLUSHING 58, NEW YORK, N. Y.

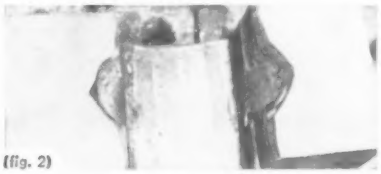
FAST OVERLAY FOR CAST IRON DIE— LOWER COST— LONGER SERVICE

Constant use was wearing away large cast-iron forming dies used by a Canadian railway car manufacturer. The company wanted any repair to be harder than the cast-iron itself.

(fig.1)

A "Eutectic" District Engineer was consulted, and recommended that the forming dies be rebuilt by overlaying with EutecTrode 130 (AC-DC).

EutecTrode 130 (AC-DC) is specially designed for a hard overlay on cast iron and steel which is subjected to constant wear. Its "Frigid Arc" coating helps produce deposits with a hardness of Rockwell C45-47 as deposited: at lowest temperatures. Slight peening and multiple layers increases this hardness to RC 62! Deposits are smooth, dense and offer exceptionally high resistance to wear and corrosion. The low welding temperatures possible with all "Eutectic" alloys avoids the difficulties of embrittlement and warping, common when conventional high heat welding materials are used on cast iron.



(fig. 2)

Figure (1) shows the building up process with EutecTrode 130 (AC-DC) well on its way. In figure (2) the die is in the final stages of being refinished with this superior alloy. The manufacturer was astonished at the results obtained. After two months of constant use the forming die blocks show virtually no wear. *(B-16)*

HIGH-HEAT DISCOLORATION ELIMINATED ON STAINLESS STEEL

The high heat needed with conventional silver solder caused discoloration of a new stainless steel mixing valve. This forced the manufacturer into an extra grinding and polishing operation, which considerably increased the unit cost.

On a regular shop call the "Eutectic" District Engineer suggested EutecRod 1801.

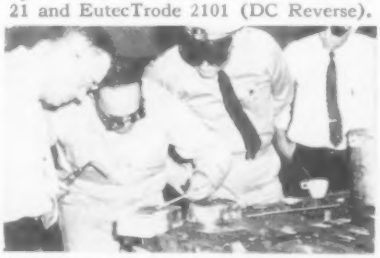
EutecRod 1801 is a universal, low-melting silver type alloy with a high tensile strength of 90,000 psi...a perfect combination for stainless steel. It is ideally suited for delicate parts and light gage metals. Tests with EutecRod 1801 showed that the lower heats possible with this "Eutectic" alloy eliminated the troublesome discoloration. Faster joints were possible too, because of the thin flowing properties of this highly developed alloy. The finished joint was strong, leakproof and corrosion resistant.

Now, using EutecRod 1801 to assemble his mixing valves, the manufacturer reports that the elimination of extra polishing and cleaning, as well as increased production, effected savings of $15,000 a year. *(B-17)*

NAVY SeaBees LEARN NEWEST ANTARCTIC WELDING TECHNIQUES

A U.S. Navy Construction Training Unit was recently instructed in the latest "Low Heat Input"® metal joining methods and alloys by a demonstration team from Eutectic Welding Alloys Corporation. The training unit was part of a Steel Working School at the Rhode Island SeaBee Construction Base. The "Eutectic" demonstration emphasized techniques and alloys specially suited for below zero service conditions. SeaBee construction crews will soon leave for the Antarctic in preparation for the U.S. Navy's participation in the 1958 International Geophysical Year.

Special attention was directed at EutecRod 21 and EutecTrode 2101 (DC Reverse).



EutecRod 21 is a torch aluminum alloy for high strength fillet and bead joints on wrought forms, extrusions and cast aluminum...ideal for architectural and general building use. EutecTrode 2101 (DC Reverse) is a new, patented electrode with *extruded* "frigid arc" flux coating. Designed for heavier aluminum castings, long joints, filling defects and overlaying, its *extruded* coating makes it easy to control. Both of these alloys have been found highly adaptable to sub zero service conditions. *(B-18)*

Q. Please give us procedure for rebuilding and hard surfacing manganese pressure jaws on gravel crushers. Conventional materials always cause distortion and buckling.

A. Manganese jaws of this type can be surfaced with EutecTrode 2 as is, or followed by subsequent layers of EutecTrode 12. For maximum impact resistance, we suggest padding of either EutecTrode 4 or EutecTrode 680 applied directly to the manganese jaws, over which apply EutecTrode 12.

Q. We would like information on overlaying nickel-manganese parts of our shot-blast unit.

A. Assuming the overlay is subjected to heavy impact in service, we would recommend EutecTrode 4. Apply directly to the nickel-manganese parent or, for extremely heavy sections, after a preheat of 500°F. Under certain conditions it is desirable to apply EutecTrode 680 directly to the nickel-manganese base metal without preheating and build up with subsequent layers of EutecTrode 4.

Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, N.Y.

Gentlemen:

I would like further free information on the following:

☐ B-16 ☐ B-17 ☐ B-18

☐ Free: New 1958 180 page pocket Welding Data Book.

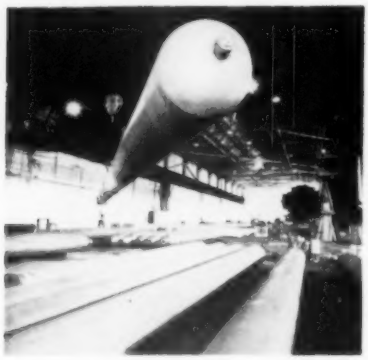
Name_____

Business Address_____

City_____ State_____

"EUTECTIC" WELDING HEADLINES • TIME-MONEY-MACHINERY SAVERS

OXYGEN CYLINDERS



Looks like a blimp but in reality it is one of thirty 80-foot oxygen cylinders made at U. S. Steel's National Tube Division's Christy Park Works in McKeesport, Pa. These cylinders will serve as part of an oxygen plant at Granite City, Ill., storing oxygen at high pressure.

Airco Acquires Hartford Firm

Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y., acquired Adelson-Werts, Inc., of Hartford, Conn., it was announced today by A. C. Brown, Jr., vice-president of Air Reduction's Eastern Region.

The Hartford firm has been an authorized dealer for Air Reduction since 1948, serving industries in the central and northwest areas of Connecticut with Airco oxygen, acetylene, nitrogen, argon, hydrogen and helium, and Airco arcwelding, Heliwelding, and oxyacetylene welding and cutting equipment and supplies.

The acquisition resulted from the retirement of S. Adelson, co-owner. Mr. Werts and the other personnel will continue at the location which becomes an exclusive Airco store. L. B. Driscoll of Air Reduction has been named store manager.

Opportunities in Civil Service

Announcement No. 112B from the United States Civil Service Commission contains in its 12-page booklet various engineering opportunities now available through Civil Service. Among the subjects discussed as prerequisites for these positions are educational background and quality of experience. Anyone interested in obtaining further information on opportunities in welding engineering should direct inquiries to: Executive Secretary, Board of Civil Service Examiners, Room 1109 Main Navy Bldg., Department of the Navy, Washington 25, D. C.

LINCOLN NAMES "DEALER OF THE YEAR"

Richard Lindgren, extreme left, district manager for Lincoln presents the "Weldealer of the Year" plaque to Russell Pulis and Richard Pumroy, owners of the Valley Supply Co., Ottumwa, Iowa. The award, given annually by Lincoln Electric Co., is extended to Valley Supply for "outstanding achievements in performance, cooperation, development and leadership." Lester Hansen, Lincoln sales engineer, is at the extreme right. The Messrs. Lindgren, Pulis, Pumroy and Hansen are members of AWS.

Appointments at Smith Welding Equipment

Lloyd L. McBurney, president of Smith Welding Equipment Corp., Minneapolis, Minn., announces two executive appointments as part of the company's program of expansion.

Robert L. Peterson, formerly with the G. H. Tennant Co., Minneapolis, has been appointed advertising manager and will supervise all space advertising, sales promotion programs and the company's participation in trade shows. He is a graduate of the University of Minnesota with a B.A. degree from the School of Journalism and has specialized in the advertising and marketing of technical products.

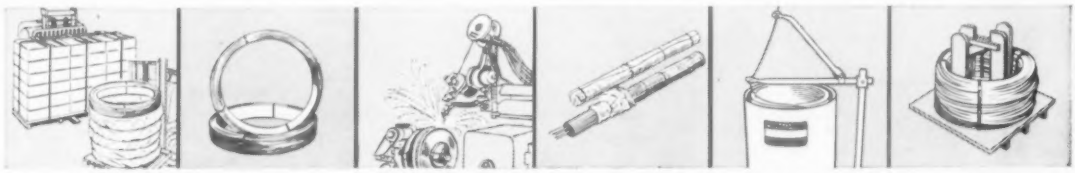
Malcolm E. Fallek, formerly with the Business and Economics Research Department of Minnesota Mining & Manufacturing, St. Paul, has been named manager of market research for Smith Welding. He is a mathematics graduate with a B.A. degree from New York State Teachers College and an M.A. degree in Marketing from the University of Iowa. He will direct market research and analysis studies.

For more details, circle No. 27 on Reader Information Card

PAGE Welding Wire

The RIGHT Packaging for the RIGHT Wire

• When you choose PAGE Welding Wire, you are assured of getting the exact wire for your application—and receiving it packaged to provide maximum protection and convenience. PAGE has developed a packaging program to cover practically every requirement in the broad fields of automatic, semi-automatic and manual welding. Coils, reels, bundles, cartons, Leverpaks, Payoffpaks, Payoff-pallets... PAGE has them all! Look to PAGE for the *right* packaging of the *right* wire.



Wrapped Coils—Coils in Cartons | Welding Wire in Coils | Handy Reels | Gas Rod Packing | Payoffpaks and Leverpaks | Payoffpallets

This Chart Shows How PAGE Offers The Exact Packaging You Want

PACKAGING ↓ / PAGE WIRE for →	Gas-shielded consumable electrodes: Automatic Welding	Gas-shielded consumable electrodes: Semi-Automatic Welding	Filler wire for automatic or manual Inert Gas Welding	Submerged Arc Welding	Straight and cut lengths Bare wire: Manual Electric Welding	Straight and cut lengths Bare wire: Oxy-acetylene Welding
25-lb. or 60-lb. coils wrapped in waterproof paper, steel-strapped, single or palletized.	✓	✓	✓	✓		
25-lb. or 60-lb. coils in individual cartons, single or palletized.	✓	✓	✓	✓		
120 or 180 lb. (22″/24″ I.D.) coils, paper-and-burlap wrapped, or in cartons, palletized.	✓			✓		
Special coil sizes (on application).	✓	✓	✓	✓		
25-lb. reels (spools) in carton to fit all standard machines; single or palletized.	✓	✓	✓	✓		
Leverpaks, 15″ dia., 25-lb. coils (12″ I.D.x2½″ wide); Leverpaks, 17″ dia. 50/60-lb. coils (12″ I.D.x4″ wide).	✓	✓	✓	✓		
Payoffpaks: 20″ dia. size holds up to 500 lbs.; 23″ dia. size holds up to 700 lbs.	✓	✓		✓		
Payoffpallets, holding 900-1200 lbs. of wire (3/16″ to 3/8″ sizes, incl.) coiled around pedestal on a wooden pallet.				✓		
Paper-and-burlap wrapped bundles, containing 50 lbs. of rods in 36″ lengths.			✓			✓
Fibreboard cartons, containing 10 lbs. of rods in 36″ lengths; single or boxed. 50# and over.			✓			✓
Burlap-wrapped 50-lb. bundles of bare wire electrodes in 14″ and 18″ lengths.			✓		✓	

33 DIFFERENT ANALYSES

PAGE covers the field of applications with *33 different analyses:* heavy automatic submerged arc..light manual submerged..inert gas manual...automatic, tungsten or metal arc, and oxy-acetylene gas welding.

Look to PAGE for your needs for automatic welding wire, gas welding rods, bare electrodes or metal spray wire.

PROMPT DELIVERY FROM LOCAL STOCKS

PAGE welding wire and rods are available from your nearby PAGE Distributor or PAGE warehouse stocks (*see list at right*).

Send for These...

- **Folder DH-402A** PAGE Submerged Arc and Inert Gas Welding Wire
- **Booklet DH-1277** PAGE Gas Welding Rods
- **Welding Rod Comparison Chart**

Page Steel and Wire Division
AMERICAN CHAIN & CABLE

ACCO

Monessen, Pa.*, Atlanta, Chicago*, Denver*, Detroit, Houston* Los Angeles*, New York, Philadelphia*, Portland, Ore. San Francisco*, Bridgeport, Conn.

**Indicates PAGE warehouse stocks*

ACCO for Better Values

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INTERNATIONAL WELDING NEWS

The East German Welding Committee

By W. Raidt

The Welding Committee of East Germany is one of 16 committees of the Machinery Section of the Engineering Chamber. The latter is the comprehensive technical organization of scientists, engineers, and other technical personnel, which endeavors to further the technical and economic progress of the German Democratic Republic. The Welding Committee has five aims: (1) exchange of information; (2) introduction of new developments; (3) broadening of technical and economic knowledge; (4) cooperation with code-uniting bodies; and (5) development of technical information. The means for attaining these aims are: (1) holding meetings and courses; (2) publishing literature; (3) sending delegations to conventions and expositions, domestic and foreign; and (4) cooperating closely with official organizations.

The Committee has ten subcommittees: (1) filler metal; (2) automatic welding; (3) welding equipment; (4) metal spraying; (5) surfacing; (6) nondestructive testing; (7) education; (8) resistance welding; (9) design; and (10) thermit welding. There are also district committees (Leipzig, Dresden, etc.) and regional committees. The main Committee has about 50 members, including chairmen of sub-committees, district and regional committees, project and standardizing committees, heads of welding institutions, and other technical people involved in welding. The chairman is elected by the members, and there is a small steering committee. In 1956 the main committee had five meetings; the steering committee had two. Each subcommittee has 10 to 20 active, qualified members. Their activities in 1956 are described below.

Filler Metal: (*a*) cooperation with East German standards group for cast-iron welding rod and for unified standards with West Germany; (*b*) classification on an international level of electrodes for submerged-arc welding; (*c*) the problem of electrodes without stripped ends, multiple electrodes, electro-slag welding, welding thick plates, special alloy electrodes; and (*d*) formation of working groups on automatic welding.

Automatic Welding: (*a*) improvement of automatic and semiautomatic apparatus for arc welding; (*b*) cooperation in developing filler metal; (*c*) advisory work in setting up equipment for producing welding material; (*d*) evaluating the characteristics of the different fluxes; (*e*) developing a universal flux to be used with the standard electrodes in submerged-arc welding; (*f*) copper coating of wire for submerged-arc welding; (*g*) issuing trip reports of delegations to Russia and Poland; (*h*) publishing information leaflets on submerged-arc welding; (*i*) holding competitions; (*j*) forming a special group on apparatus; and (*k*) cooperation with the resistance-welding subcommittee.

Gas Welding Equipment: (*a*) evaluation of all tests on equipment made by the Central Welding Institute; (*b*) evaluation of foreign automatic welding processes; and (*c*) working on cutting apparatus, powder cutting and standards.

Metal Spraying: (*a*) forming three working groups, one at the Central Welding Institute on equipment, one at Rostock on corrosion prevention in ships, and a third at Halle on corrosion prevention in industry; other groups will be formed later; (*b*) spreading information particularly in cooperation with the Educational Committee; and (*c*) holding an international conference on metal spraying in conjunction with the Central Welding Institute.

Surfacing: (*a*) spreading information on surfacing and setting up qualification courses for welding operators doing surfacing; and (*b*) cooperate with the automatic welding committee in developing a fully automatic machine for surfacing rails.

Nondestructive Testing: (*a*) cooperation with the main committee of the Chamber on Materials Testing; (*b*) use of isotopes and ultrasonic methods in industry; (*c*) hold a conference on nondestructive testing early in 1957; and (*d*) prepare an atlas of radiographs.

Education: (*a*) review existing educational literature with particular reference to codes; and (*b*) prepare training courses on hot-welding cast iron, welding copper, inert-gas welding, light-metal welding, submerged-arc welding, and metal spraying.

Design: (*a*) deal with all questions of design on a scientific plane; (*b*) hold an international conference; (*c*) issue methods of calculating welded machine structures; (*d*) investigate the action of combined side and end fillet welds; (*e*) investigate safety factors; and (*f*) comprehensive evaluation of international literature.

Thermit Welding: (*a*) development of methods for rail and repair welding; and (*b*) assist the Educational Committee in preparing a course of instruction.

On Nov. 28, 1956, the Welding Committee issued the following statement in an endeavor to unify the somewhat divergent reports of the three delegations that visited Russia.

"Present Position in East Germany.

1. Welding represents a relatively high proportion of production, compared with casting and riveting.
2. Manual welding is at a high state of development from the standpoint of quality of electrodes and weld metal.
3. Welded products are well designed.
4. From both material and man-hour standpoints, welding is being performed economically.
5. Deficient in automatic welding, resistance welding, and fabricating techniques.

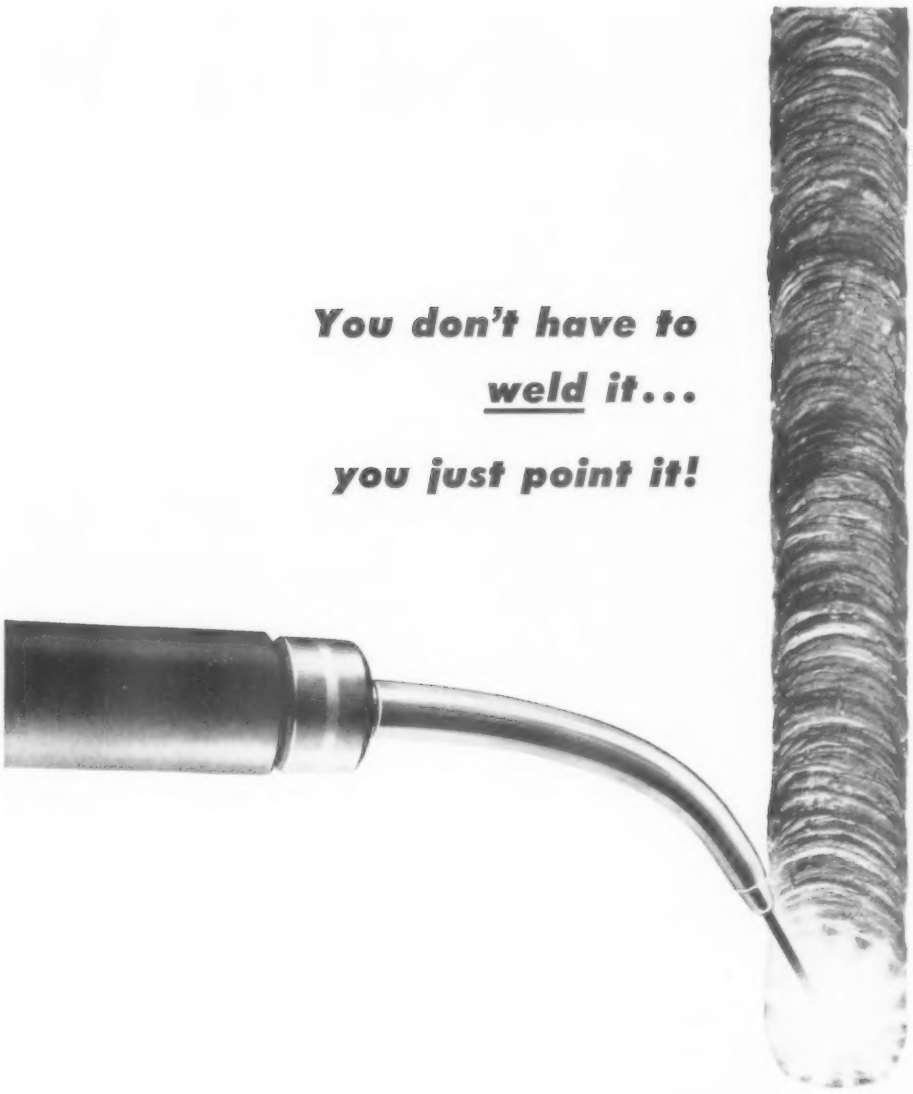
"We cannot adopt the Russian scheme of things, but should endeavor to develop the following Russian innovations:

1. Highly developed equipment for submerged-arc and inert-gas welding.
2. To a small extent introduce electro-slag welding.
3. Study Russian research on strength of materials.

"The fields in which we lead are:

1. Welding with particular emphasis on low cost.
2. Electrodes with high deposition rates.
3. Sintered flux.
4. Use of highly developed resistance welding.
5. Lightweight structures.
6. Use of structural steels, such as ST52, that are free from cracking tendencies."

Abstract by Gerard E. Claussen of "Der Fachausschuss Schweisstechnik," published in Schweisstechnik (Berlin), **7**, 33-35 (1957). The author is Chairman of Committee. Dr. Claussen is associated with Development Laboratory, Linde Co., Newark, N. J.



You don't have to

weld it...

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STOODY SEMI-AUTOMATIC HARD-FACING

The fast way to take the work out of welding!

Hard-facing with the new Stoody Semi-Automatic Wires is *that* easy! You simply "aim" the wire and strike the arc. The semi-automatic machine does the rest... automatically feeds the wire at the correct rate, lays down a sound deposit—stringer bead or wash pass.

Man, it's a weldor's dream! No fluxes, no flux dams. Perfect visibility of the weld every inch of the way. And talk about speed—2 to 4 times faster than manual welding... ideal for covering big areas quickly, extremely handy for maintaining equipment between shifts! No changing of electrodes either... welding is continuous as long as there's wire on the reel and this naturally means an end to stub end waste.

With Semi-Automatic's low heat input and low penetration, there's less dilution of the deposit. *Less dilution* means *higher alloy content* with increased wear resistance, usually superior to manual electrodes of similar analysis. There's a complete line of wires with just the right analysis for every job!

TRY SEMI-AUTOMATIC HARD-FACING THIS EASY WAY—Your Stoody dealer will arrange for a semi-automatic demonstration in your plant—on your own job. (Check the yellow pages of your phone book for nearest Stoody Dealer.) Let him prove how Stoody Semi-Automatic Hard-Facing can cut your maintenance costs!

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PERSONNEL

Callahan Completes 40 Years of Service

John F. Callahan, assistant advertising manager, Air Reduction Sales Co., on August 11 celebrated completion of forty years of service with the company. Mr. Callahan is among the first of a small group of pioneers to reach the forty-year mark with Air Reduction.

Mr. Callahan started with Air Reduction in 1917 as a messenger in the

John F. Callahan

mail room of the company's headquarters then located at 120 Broadway, New York City. On March 1, 1921, he joined the company's advertising department where since 1938 he has been assistant advertising manager.

In addition to having served as a member of the Program and Publicity Committee of the AMERICAN WELDING SOCIETY, Mr. Callahan has for the past twenty-eight years been a member of the Program, Publicity and Arrangements Committee of the International Acetylene Association. He is also secretary of the Air Reduction Quarter Century Club and a director of the Airco Association, Inc.

Dana and Swan Named by Union Carbide

L. I. Dana has been appointed vice-president—research and development, and David Swan appointed director of research of Linde Co., Division of Union Carbide Corp., it was announced by W. M. Haile, president of Linde. Dr. Dana has been, up to now, vice-president—research for Linde. Mr. Swan has been director of research of Metals Research Laboratories, Electro Metallurgical Co., another Division of Union Carbide.

Dr. Dana joined Union Carbide in 1923 at the Linde laboratory, in Buffalo. He became director of the laboratory in 1931 and held that position until 1943 when he was transferred to the New York office as research manager for the Linde laboratories at Tonawanda and Indianapolis. He was named vice-president—research of Linde in 1951. Dr. Dana directed the work that resulted in a safe and practical method of distributing large shipments of liquefied oxygen and nitrogen.

Mr. Swan has been with Union Carbide since 1946 when he joined the research laboratories of Electro Metallurgical Co. at Niagara Falls. In 1947 he was transferred to the New York offices of Electro Metallurgical Co. as a research engineer. He moved back to Niagara Falls in 1952 when he was appointed assistant director of research for the laboratories and, in 1955, he was made director. Mr. Swan is the author of numerous papers in the fields of welding and metallurgy. He was graduated from Rensselaer Polytechnic Institute in 1940 with the degree of B.S. in Metallurgical Engineering, and is a member of the AMERICAN WELDING SOCIETY.

Purdy Named by Westinghouse

The appointment of Fred J. Purdy to the newly created post of manager of marketing for the Westinghouse welding department has been announced by R. C. Lipps, manager of the department. Mr. Purdy's promotion from sales manager recognizes that marketing responsibilities logically encompass the complete movement of product from production point to point of sale. His organization includes headquarters marketing personnel in Buffalo and a nation-wide field sales force.

Mr. Purdy is a graduate of Bowdoin College; he also attended Harvard Business School and Boston University Law School. He has been with Westinghouse since 1944. Mr. Purdy is a member of the AMERICAN WELDING SOCIETY.

Kurzinski Joins Air Products

Edward F. Kurzinski has joined Air Products, Inc. of Allentown, Pa., as manager of sales development engineering. He will assist both the ferrous and nonferrous metals industries, and other related industries, in their problems relating to the use of oxygen and other industrial gases.

Mr. Kurzinski has made substantial contributions to oxygen application in open hearths, electric furnaces and pneumatic steelmaking techniques including decarbonization, combustion and desiliconization of hot metal. He also has developed various techniques for the desulfurization of ferrous metals, primarily nitrogen-conveyed calcium carbide. He has several patents in the field of metallurgical processes and was previously Laboratory Division Head at the Linde Co.

Fitzgerald Promoted by Alloy Rods

John Fitzgerald has been promoted to the position of manager of field sales for Alloy Rods Co. E. R. Walsh, III, vice-president in charge of sales, in announcing the newly created position, states that Mr. Fitzgerald will assist

John Fitzgerald

F. L. Blodgett, general sales manager, in the administration of sales policies at the company's branch offices and distributor sales organization.

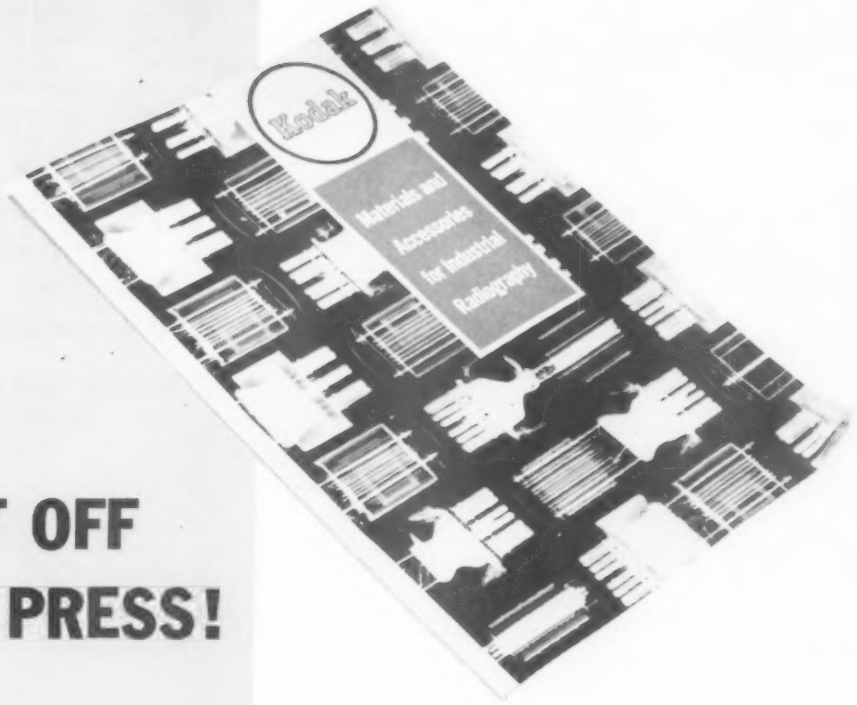
Mr. Fitzgerald has been with Alloy Rods Co. for a number of years and served in the capacity of field representative at the company's Pacific coast sales offices and at the Newark, N. J., branch. He has had considerable experience with both distributor and consumer sales.

Mr. Fitzgerald is a member of AWS.

Bender Appointed by Blaw-Knox

Michael Bender has been appointed metallurgist and welding engineer with Blaw-Knox Co.'s Buffovak Equipment Division, Buffalo, N. Y.

In his new position he will develop all division welding procedures, advising and assisting the engineering, manufacturing, inspection and sales



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A gold mine of information on the choice of x-ray films for today's radiographic inspection procedures.

This 16-page booklet is far more than an ordinary catalogue. It lists and describes the latest Kodak X-ray Films and accessories. It goes much further. It gives the characteristics of these fast films and provides charts that aid you in selecting the correct film for various applications and sources of radiation.

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And You're Ready to GO on ANY Job!

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TORCHIE has revolutionized Torch Lighting EVERYWHERE and once you test it, you'll never part with it. Just SWISH your Torch over TORCHIE and BINGO!—an *instantaneous never-failing light*—costs only $9.95

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departments on metallurgical and X-ray problems, welding techniques, material and equipment.

Before joining Blaw-Knox, Mr. Bender was associated with Air Reduction Sales Co. He was formerly with Blaw-Knox Co.'s Equipment Division at Blawnox, Pa., as a metallurgist and chief inspector. He has also been associated with Pittsburgh-DesMoines Steel Co. and Babcock and Wilcox Co., Beaver Falls, Pa.

A native of Pittsburgh, Mr. Bender received his bachelor's degree in metallurgical engineering at the University of Pittsburgh and has attended the Carnegie Institute of Technology school of industrial management.

OBITUARY

Irving Langmuir

Dr. Irving Langmuir, world-famous scientist, died at Falmouth, Mass., on Friday, Aug. 16, 1957. He was 76 years old.

The Nobel-prize winning scientist, often regarded as one of the scientific geniuses of modern times, was on the staff of the General Electric Research Laboratory from 1909 until his retirement in 1950.

Dr. Langmuir was largely responsible for the development of atomic hydrogen welding permitting for the first time, the easy welding of aluminum and chromium and other hitherto unweldable metals and the joining of extremely thin sheets of metal, which would be burned by other processes.

•

EMPLOYMENT SERVICE BULLETIN

Positions Vacant

Sales Director required to initiate and manage nationwide distribution system for complete new line of Precision Flame Cutting Machines. The applicant selected must possess a high degree of ability and drive.

Send complete resume and salary requirements to American Messer Corp. 405 Lexington Ave., N. Y.

V-348. Welding Engineer—familiar with all types of welding methods with emphasis upon inert-gas welding, particularly with carbon-dioxide shielding. Requires knowledge of all types of welding power units. Promotional work. Submit complete résumé including past earning power and present salary requirement.

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Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

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METALLURGISTS

Positions offering unusual professional growth opportunities with expanding Atomic Energy Division of long established manufacturer of power generating equipment. Minimum requirements—degree plus experience in practical metallurgy and fabrication of carbon and stainless steels. Knowledge of fuel element fabrication and/or other metallurgical and fabricational applications peculiar to atomic power generation desirable but not essential. Send resume and salary requirements to:

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Employee Services Department

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WELDING ENGINEER

To supervise *Flash Welding* chain by automatic equipment of German and Swedish design. Excellent opportunity. All applications will be held in strict confidence. Salary open for negotiation.

Write and enclose resume or call

J. F. Kestner

P. O. Box 350 Chester, Pa.

Phone Chester 3-9271

For heavy plate to thinnest alloys

VICKERS Controlarc*

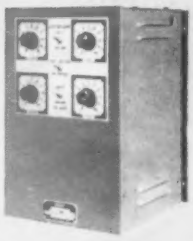
MAGNETIC AMPLIFIER DC WELDER... AND ACCESSORIES

- Maintains arc stability through the complete current range from extremely low to extremely high without range switches.
- Bends the volt-ampere curve to meet the particular welding job being done.
- Full-range automatic arc control in any welding position.
- Strikes an arc without the use of high frequency when using inert gas and tungsten on lowest currents.
- Exclusive, patented Magnetic Amplifier combines fine control with ruggedness and durability.
- Exclusive, *dual* remote control equipment available . . . provides close control of current and voltage range.
- Low spatter performance on special electrodes.

*TRADEMARK

Write for complete information on this equipment and for other high quality—high performance welding machines under development.

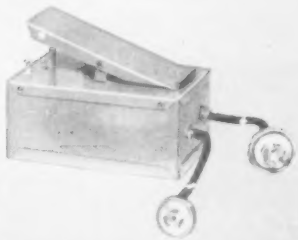
SLOPE CONTROLLER
for automatic tungsten inert gas welding; using Vickers standard *drooping* (not constant potential) output welding power source. Linear—static—exclusive design.



INERT GAS WELDING CONTROL UNIT
With or without timer adjustable pre-flow of inert gas and water.

INERT GAS SPOT WELDING TIMER UNIT
for TIG guns which are high frequency started (Tungsten contact not required for initiation). Timer calibrated for 3 to 360 cycles.

REMOTE HAND AND FOOT CONTROLS
Many designs available for special applications.



CONSTANT POTENTIAL ADAPTER UNIT
Converts standard welder to constant potential power source for semi-automatic or automatic welding heads and guns.

CONSTANT POTENTIAL POWER UNITS
for automatic and semi-automatic production welding.

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DIVISION OF SPERRY RAND CORPORATION
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For more details, circle No. 33 on Reader Information Card

NEW LITERATURE

Welding of Steel Castings

The Steel Founders' Society of America announces that a manual entitled "Recommended Practice for Repair Welding and Fabrication Welding of Steel Castings" is now available.

This manual replaces an earlier publication entitled "Recommended Practice for the Welding of Steel Castings" first issued by the Steel Founders' Society in 1951.

The Steel Foundry Research Foundation sponsored and directed the necessary research for the preparation of the new manual at Battelle Memorial Institute under the guidance of Charles W. Briggs, research director of the Steel Foundry Research Foundation. Publication, and subsequent distribution, was assigned to the Steel Founders' Society of America.

The 1957 manual incorporates the many developments in welding procedure since 1951 and features a comprehensive listing of the AMERICAN WELDING SOCIETY Classified Mild Steel and Low Alloy Electrodes.

Divided into three sections, the manual covers welding methods, electrodes and recommended welding procedures for carbon steel and low alloy castings with each general alloy series indexed for quick reference.

Copies are available at 50 cents each from the Steel Founders' Society of America, 606 Terminal Tower Building, Cleveland 13, Ohio.

Oxyacetylene Welding

The role of the oxyacetylene flame in speeding ship repair and fabrication work is described in a new six-page booklet (Form 1102) prepared by Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y. Modern oxyacetylene processes, such as flame-planing, rivet-busting, mechanized shape-cutting and gouging are illustrated and described, along with apparatus requirements.

For your free copy, circle No. 34 on Reader Information Card.

Positioners

Aronson Machine Co., Arcade, N. Y., offers their new twelve-page bulletin No. TR57 featuring a variety of tank turning rolls, pipe rolls and rail cars for positioning cylindrical vessels for automatic welding. Complete specifications are given such as, diameter settings, speeds, tire sizes and tractive pull ratings for unbalanced vessels. According to the manufacturer, the Aronson rolls have been designed to carry maximum loads at all speed settings and the speeds can be controlled to within $^1/_{10}$ ipm. Heavy construction and precision jig-drilled ways are featured on every type roll. The Aronson rolls can handle vessels up to 600 tons in any lengths.

For your free copy, circle No. 35 on Reader Information Card.

Farm Welding

For farms and farm implement suppliers, a new 28-page, illustrated "Farm Maintenance Welding Issue" of the biweekly Technical Information Digest (TIS 2837) has been published by the Technical Information Service, Eutectic Welding Alloys Corp., Flushing 58, New York, N. Y.

Primarily for the farm equipment repair shop, the booklet uses over 60 illustrations, many the before and after type, to show the wide range of tools and equipment economically salvaged with "low heat input" welding.

According to the manufacturer, the issue treats practical repair problems, gives ideas on how to salvage rather than replace damaged or worn parts. Illustrations show scores of actual farm parts of cast and malleable iron, of mild to high alloy steels, and of aluminum. These typify the unlimited number and types of parts that any farm repair shop can salvage to effect minimum downtime losses.

For your free copy, circle No. 36 on Reader Information Card.

Electrode Guide

A new seventy-page "electrode pocket guide" (form ADC 650G) which contains information of interest to those concerned with buying or using electrodes is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Among the features of the booklet is an electrode consumption calculator, in tabular form, which provides data for calculating consumption per linear foot in the welding of various types of joints.

The guide describes each Airco electrode, its color code, its application and the best procedure for its use in welding. Weld-metal chemical analyses and mechanical properties are fully explored. Such related information as the factors which determine electrode selection, industrial and government specifications for filler metals and testing of deposited weld metal is also discussed.

For your free copy, circle No. 37 on Reader Information Card.

Copper Alloys

The third quarter 1957 issue of the Ampco Welding News, published by the Weldrod Department of Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis., is now available for distribution.

The lead story pertains to the welding of Ampco Grade 18 (aluminum bronze) propeller shafts for the Mexican shrimp boat fleet.

Also featured is an interesting résumé of original research work involving the joining of 90–10 cupro-nickel with ECuAl-A2 and the inert-gas consumable-electrode process.

Other articles include the overlay of paper coating rolls; the reclamation of bronze pickling hooks; the Ampco-Facing of automobile molding dies; etc.

For your free copy, circle No. 38 on Reader Information Card.

Resistance Welding

Resistance Welder Corp., Bay City, Mich., has issued a new pictorial bulletin number PTW 5701 on press-type welders and tooling.

This bulletin illustrates standard type press welders with examples of various types of special tooling for increasing production on small to medium size welded assemblies.

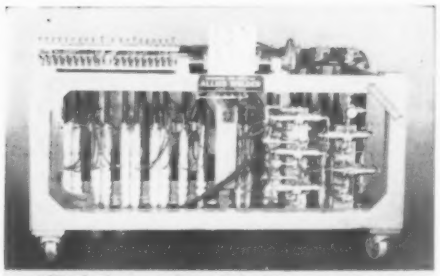
For your free copy, circle No. 39 on Reader Information Card.

Radiography Materials

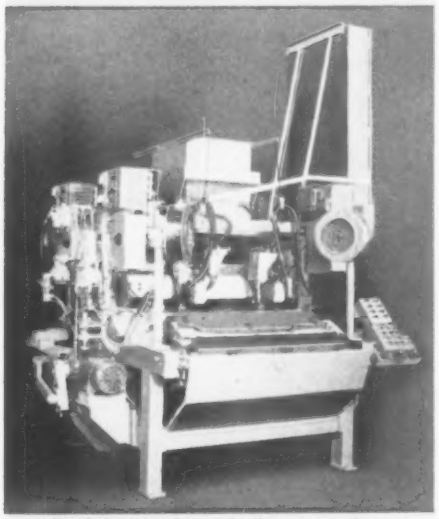
The complete line of Kodak industrial radiographic materials are illustrated and described in a new pamphlet, "Materials and Accessories for Industrial Radiography," published by Eastman Kodak Co., Rochester 4, N. Y.

This booklet contains a guide chart for selection of Kodak film for various material thicknesses.

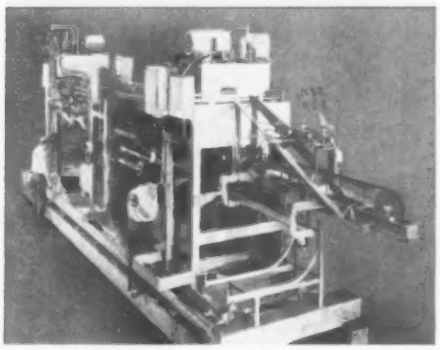
Recommended development techniques are also listed in chart form com-



Allied designed and built air operated machine for drilling 20 holes simultaneously in trailer floor.



Allied designed and built automatic over and under arc welder. Welds automotive frame X member.



Allied designed and built automatic two-stage resistance welder with transfer and turn over devices. Welds radiator support assembly.

how big is your problem . . .

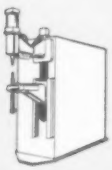
Really?

If it involves special equipment for a production welding operation it may not be a problem at all—just an assignment when placed in competent hands.

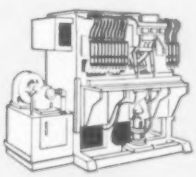
This is our kind of work – we specialize in it – do it every day; designing and building special machines for welding everything from bathtubs to trailers, frequently including provisions for automatic handling and transfer where the job is a part of a production line set-up.

We're no brain trust here at Allied Welder, but we keep some awfully important production people happy with our creative designing and manufacturing know-how, delivery, too.

May we work with you on your next job?

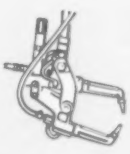


Standard Welders



Special Welders

Automation Equipment



Automatic Arc Welders

Welding Guns

ALLIED WELDER CORPORATION

8700 BRANDT DEARBORN, MICHIGAN

Creative Design

For more details, circle No. 40 on Reader Information Card

paring the characteristics of Kodak Industrial X-Ray Film, Type M (extra fine grain and high contrast); Type AA (fine grain, high contrast); Type K (fast, direct exposure film); and Type F (high speed—with fluorescent screens).

For your free copy, circle No. 41 on Reader Information Card.

Brazing

Number 77 of "Handy News," published by Handy & Harman, 82 Fulton St., New York 38, N. Y., contains a 2-page article entitled "The Honeycomb Sandwich," a description of the high-temperature brazing alloys used in the manufacture of the Air Force bomber, the B 58. A page is also devoted to brazing procedures used in making "Ronson" lighters.

For your free copy, circle No. 42 on Reader Information Card.

Hard Surfacing

A new 8-page booklet entitled "Haynes Hard-Facing Electrodes" is now available from Haynes Stellite Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y. This booklet describes the chemical composition, some properties, typical applications, application procedures and packaging for the 12 Haynes alloys that are available as electrodes. These include eight iron-base alloys, three cobalt-base alloys and Haystellite cast tungsten carbide.

For your free copy, circle No. 43 on Reader Information Card.

Memco News

Volume 8, Issue 4 of "Memco News," is available from Miller Electric Mfg. Co., Appleton, Wis. Known as an "air age issue," the 28-page booklet examines welding's role in aircraft, rockets and missiles. Included is an article by Russell Meredith, North American Aviation, entitled "Development of the Inert Gas Arc Welding Process." The backgrounds of major aircraft companies are detailed, accompanied by many photographs. As an added feature, an 8-page insert with sketches of J. T. Trowbridge's poem, "Darius Green and His Flying Machine," is attached to each copy.

For your free copy, circle No. 44 on Reader Information Card.

Coatings

Shieldalloy Corp., Newfield, N. J., announces the availability of an 18-page brochure which lists the company's regular line of metals and alloys together with their guaranteed and typical analyses. These products are the master alloys and pure metals produced by the firm for commercial, air and vacuum-melting applications.

For your free copy, circle No. 45 on Reader Information card.

Metal Cleaning

The Wheelabrator Corporation, 600 S. Byrkit St., Mishawaka, Ind., manufacturers of airless blast equipment and steel abrasives, have published Vol. 17, No. 4 of "Wheelabrator Digest," a 16-page periodical, describing the use of airless abrasive blast cleaning in various applications.

For your free copy, circle No. 46 on Reader Information Card.

Oxyacetylene Welding Torch

The Oxweld W-47, an entirely new welding blowpipe capable of welding metal thicknesses from 28-gage sheet to 3-in. plate is described in a new eight-page booklet available from Linde Co., Division of Union Carbide Corp.

According to the manufacturer, a unique feature of new blowpipe is its ability to handle gas flows as low as 2 cu ft per hr for precision welding, or total flows as high as 1500 cu ft per hr for heavy heating operations. Cutting attachments that quickly convert the new W-47 from welding and heating to flame cutting on all metal thicknesses up to 8-in. are also described.

Complete information and performance data on welding heads and cutting nozzles is also included in the new folder.

For your free copy, circle No. 47 on Reader Information Card.

Resistance Welding

The Taylor-Winfield Corp., of Warren, Ohio, announce the availability of their latest issue, No. 578, of "Weld-It." Featured are articles on the application of resistance welding in the automotive and munitions industries.

In the latter case, mention is made of an article by Hussey and Betz which appeared in the August 1956 issue of THE WELDING JOURNAL.

For your free copy of "Weld-It," circle No. 48 on Reader Information Card.

Electrode Holder

The Lincoln Electric Co., Cleveland 17, Ohio, have issued a 4-page folder in color which describes their "Cooltong" fully insulated electrode holder. Capable of handling 300- and 400-amp currents, the holder was designed, according to the manufacturer, to remain cool under operation, to be light in weight,

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

FOR WELDING AND CUTTING...

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For more details, circle No. 49 on Reader Information Card

to withstand rough treatment and to maintain proper balance.

For your free copy, circle No. 50 on Reader Information Card.

Welding Problems

A new eight-page illustrated "Special-Loy" guide pamphlet (TIS 2836A) is available from the Technical Information Service, Eutectic Welding Alloys Corp., Flushing 58, New York, N. Y.

The two-color folder explores practical welding problems welders encounter on all common base metals. New methods are discussed of "low-heat input" welding, brazing and soldering that can sharply reduce the time duration of a metal-joining job.

Sample problems covered in the "Special-Loy" guide include methods for welding crack-sensitive and heat-treatable steels, how to fill, seal and build up heat-sensitive cast iron alloys and directions to take the "guess work" out of aluminum and magnesium joining.

Other sections give time-saving hints on tool-tipping, electrical work and similar precision jobs where heat control and alloy flow control are critical.

Special welder accessories and chemical aids that speed output by reducing set-up and post-welding time are also described. In addition, more economical techniques to hard surface and case harden metals for longer productive life, are treated.

For your free copy, circle No. 51 on Reader Information Card.

REVIEWS
OF NEW BOOKS

Design of Machines

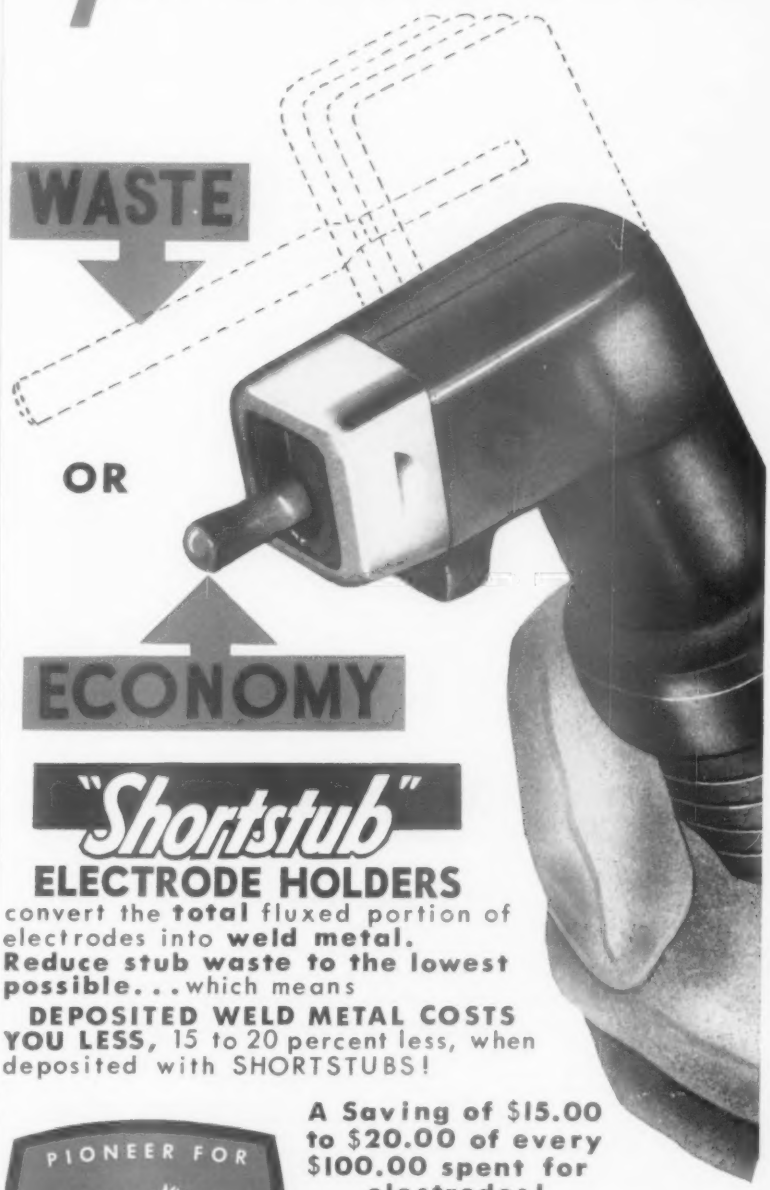
Design of Machines, by Rolland T. Hinkle, professor of mechanical engineering, Michigan State University, cloth-bound book. Price $4.00. 188 pages. Prentice-Hall, Inc., Englewood Cliffs, N. J.

In chapters 2 and 3 the theory learned in mechanics of materials is synthesized and illustrated with design applications. Additional theory is presented and much of it is applied in the 20 short problems in Chapter 4.

The long problems, presented in Chapters 6 through 11, can be used for projects or broken down into shorter problems. Subjects covered in this section include natural-frequency oscillating conveyor, thrustor brake, gear reducers, 30-ton yoke riveter, deflection of non-uniform beam and manual lift truck.

A 46-page appendix contains design data compiled in tabular and diagrammatic form.

Which do you have?



"Shortstub"
ELECTRODE HOLDERS
convert the **total** fluxed portion of electrodes into **weld metal.**
Reduce stub waste to the lowest possible. . . which means
DEPOSITED WELD METAL COSTS YOU LESS, 15 to 20 percent less, when deposited with SHORTSTUBS!

A Saving of $15.00 to $20.00 of every $100.00 spent for electrodes!

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CHICAGO 17, ILLINOIS
Contact your local distributor

For more details, circle No. 52 on Reader Information Card

NEW PRODUCTS

Iron-Powder Electrode

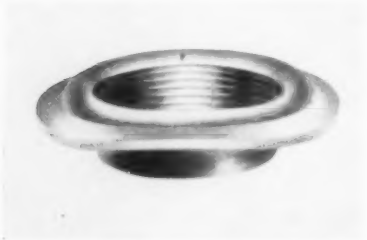
Hobart Brothers Co., Troy, Ohio, announces a new iron powder electrode for E-6010 type requirements. Using the free arc or drag technique, this electrode is said to provide a shallow rippled, smooth weld deposit in all positions, including vertical down.

According to the manufacturer, "Rocket 10-IP" is suitable for applications requiring high tensile strength, ductility, and X-ray quality such as high pressure mild steel piping, pipe lines, structural steel work, shipbuilding, and, in particular, areas where out of position welding is met.

For more details, circle No. 53 on Reader Information Card.

Welding Flange

Tech Products, Inc., 442 Mosel Ave., Staten Island 4, N. Y., have added a "2-in. heavy-duty pressed-steel" welding flange to their standard line of flanges. Additional heavy-duty sizes



ranging from $2^1/_2$ through 4 in. will soon be available.

Pressed-steel welding flanges are presently manufactured in eight sizes from $^1/_4$ through 2 in. Also available in brass, copper and stainless steel, they can reportedly be supplied to fit the contour of the intended product. Thickness of material is from 10 gage through $^3/_{16}$ in.

For further details, circle No. 54 on Reader Information Card.

Aluminum Bronze

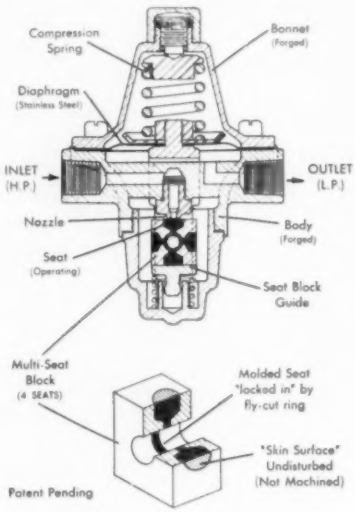
Ampco Metal, Inc., Milwaukee, Wis., has released a modified Ampco-Trode 160 in spooled wire form for joining and overlay with the inert-gas consumable-electrode process. The modified wire conforms to AWS-ASTM classification E Cu Al-B.

According to the manufacturer, Ampco-Trode 160—developing tensile strengths up to 100,000 psi and hardnesses of 190–220 BHN—is recommended for joining the higher strength, harder aluminum bronzes, such as Ampco Metal Grades 16, 18 and 20.

For more details, circle No. 55 on Reader Information Card.

Regulator

Modern Engineering Co., 3411 Pine Blvd., St. Louis 3, Mo., has introduced a pressure-molded, multi-seat block for industrial regulators which reportedly prevents the loosening and falling out of seating material.

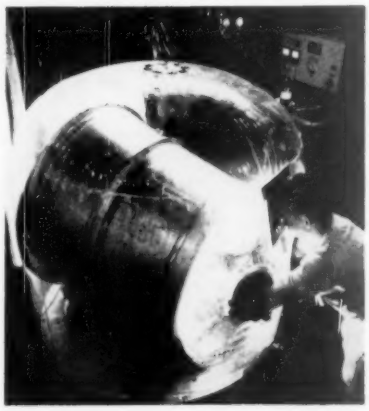


The manufacturer reports that extended tests indicate that, under identical working conditions, the new, pressure-molded, multi-seat blocks will assure an operational life equal to four times that to be expected from the conventional regulator employing single-seat design.

For more details, circle No. 56 on Reader Information Card.

Plastic Bubble

A plastic bubble is helping the aircraft industry build better jet engines, according to a release from Bakelite Co., Division of Union Carbide Corp. Made of Krene cast vinyl plastic, it has helped solve the problem of providing an easy-to-set-up, inert-gas enclosure in which to weld titanium engine parts. This plastic is exceptionally tough and highly resistant to tearing. It is light



in weight and easy to fabricate by a variety of techniques. Transparent and flexible, it has a very low gas transmission rate. Used in a welding tent, it simplifies the fabricating of such parts as a titanium compressor case, shown here at Pratt & Whitney Aircraft, Division of United Aircraft Corp., East Hartford, Conn. When titanium is welded in the presence of oxygen, impurities occur at the joint. By filling the welding chamber with an inert gas, the possibility of producing welds without impurities is greatly improved.

For more details, circle No. 57 on Reader Information Card.

Cable Splicer

A welding cable can be spliced with sound electrical efficiency in just two minutes with the new Tweco ball-point cable splicer, according to an announcement by Tweco Products, Inc., Wichita, Kan.

The new Tweco cable splicer, No. BP-230, is made from a specially designed extrusion of high-conductivity aluminum. Two $^9/_{16}$-in. diam cadmium plated-steel ball-point screws are properly located at right angles to the

1146

THE WELDING JOURNAL

Murex electrodes helped in the construction of this huge shovel capable of removing 100,000 tons of overburden in one day.

How to Build 4½ Million Pounds of Power Shovel . . .

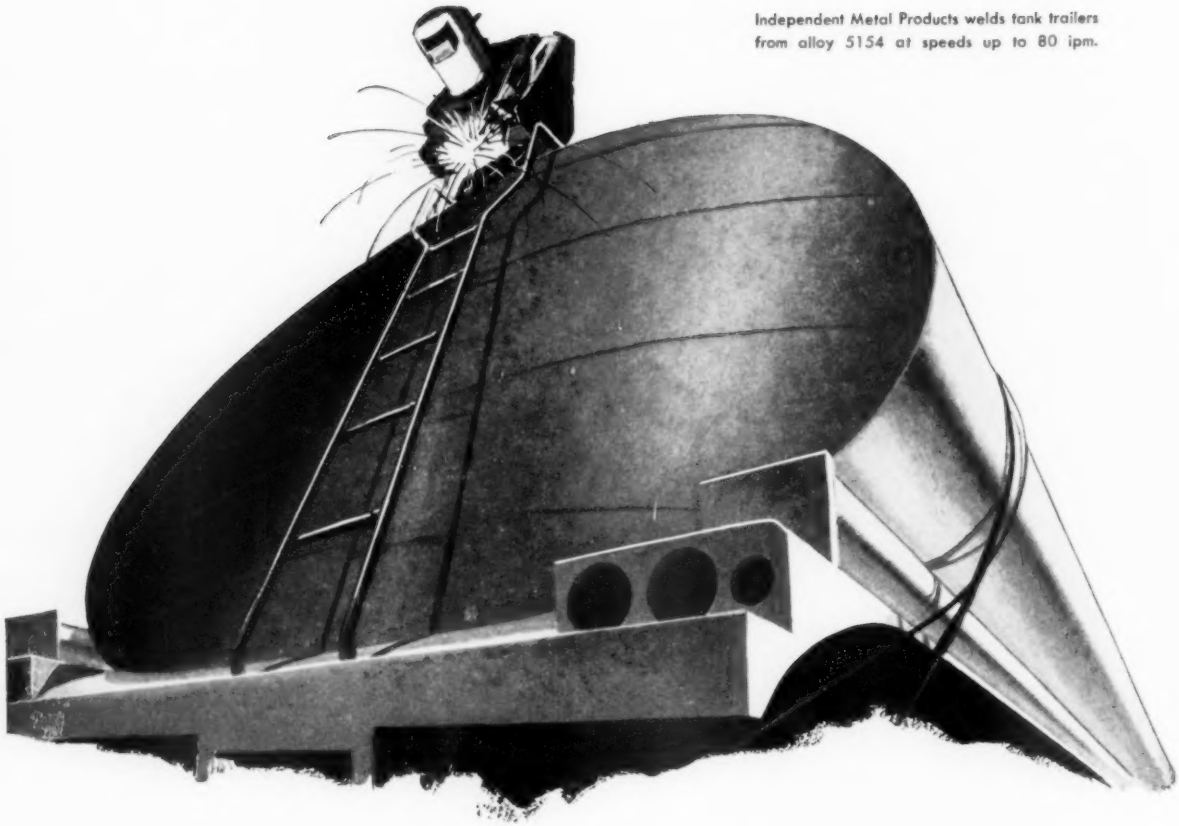
Fabricating the "River Queen", a 13-story high steel giant that weighs as much as a Navy destroyer, calls for the kind of engineering Bucyrus-Erie knows how to handle. One of the nation's foremost designers and builders of power shovel equipment, Bucyrus-Erie used the latest welding techniques, tailoring each weld to resist the strains of the big machine as it bit off 80-ton chunks of mountain and dumped them 300 feet away.

Frame, boom, bucket and its other vital parts had to be rugged to withstand the 100,000-ton-per-day earth-moving pace for which the "River Queen" was designed. Electrodes were therefore selected for their ability to produce sound, reliable, impact-resistant welds.

The task of selecting electrodes to meet the specific demands of any welding job even as complex as the "River Queen" has been simplified in a new 24-page "Electrode Selector" prepared by Metal & Thermit. Welders, designers, specifications engineers, and purchasing men who use this guide, readily find the correct rod or wire for any particular welding application. Free copies of this handy new tool for the welding trade are available from the

METAL & THERMIT CORPORATION
Rahway, New Jersey

For more details, circle No. 58 on Reader Information Card



Independent Metal Products welds tank trailers from alloy 5154 at speeds up to 80 ipm.

They're welding aluminum tank trailers at speeds up to 80" per minute!

Alcoa's 5154 alloy is going over big with trailer builders such as Independent Metal Products Division of Fruehauf Trailer Company.

It has good forming characteristics combined with great strength and ductility in welded sections. Moreover, it can be welded at speeds up to 80 inches per minute by the inert-gas shielded arc consumable-electrode welding method.

Production welds of alloy 5154, using parent alloy for filler wire, have excellent ductility . . . 39% elongation in the weld metal when a joint is bent until it fails.

With these improvements, aluminum tank trucks make substantial weight savings—savings that are turned into extra payload profit. At the same time, tank shell strength is increased . . . and accident damage is reduced. Aluminum tanks absorb substantial distortion without cracking or weld failure. One large tank truck operator says:

"In actual operating conditions—5,175,000 miles—our aluminum tanks have proved to be safer than tanks constructed of steel, particularly in resistance to rupture on overturn."

Alcoa® is headquarters for fresh, exciting ideas on how to weld, braze or solder aluminum. Get in touch with us. Where? See information at right.

* * *

Learn how easy it is to weld, braze or solder aluminum. Write for free, informative books and films. Aluminum Company of America, 1741-L Alcoa Building, Pittsburgh 19, Pa.

NEW! "ALCOA THEATRE"
EXCITING ADVENTURE
ALTERNATE MONDAY EVENINGS

Your Guide to the Best in Aluminum Value

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Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office, listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

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Birmingham
Hinkle Supply Co.
CALIFORNIA
Los Angeles
Ducommun Metals & Supply Co.
Pacific Metals Company, Ltd.
San Francisco
Pacific Metals Company, Ltd.
COLORADO
Denver
Metal Goods Corp.
FLORIDA
Jacksonville
J. M. Tull Metal & Supply Co., Inc.
Miami
J. M. Tull Metal & Supply Co., Inc.
Tampa
J. M. Tull Metal & Supply Co., Inc.
GEORGIA
Atlanta
J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.
ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.
Moline
Machinery & Welder Corp.
KENTUCKY
Louisville
Williams and Co., Inc.
LOUISIANA
New Orleans
Metal Goods Corp.
MARYLAND
Baltimore
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Bladensburg
Southern Oxygen Co.
Salisbury
Southern Oxygen Co.
MASSACHUSETTS
Cambridge
Whitehead Metal Products Co., Inc.
MICHIGAN
Detroit
Steel Sales Corp.
MISSOURI
Kansas City
Metal Goods Corp.
St. Louis
Metal Goods Corp.
NEW HAMPSHIRE
Nashua
Edgcomb Steel of New England, Inc.
NEW JERSEY
Harrison
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Merchantville
Southern Oxygen Co.
Vineland
Southern Oxygen Co.
NEW YORK
Albany
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Buffalo
Whitehead Metal Products Co., Inc.
New York
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Syracuse
Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.
NORTH CAROLINA
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Southern Oxygen Co.
Charlotte
Southern Oxygen Co.
Greensboro
Southern Oxygen Co.
Raleigh
Southern Oxygen Co.
OHIO
Cincinnati
Williams and Co., Inc.
Cleveland
Nottingham Steel & Aluminum Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
Toledo
Williams and Co., Inc.
OKLAHOMA
Tulsa
Metal Goods Corp.
OREGON
Portland
Pacific Metal Co.
PENNSYLVANIA
Philadelphia
Edgcomb Steel Co.
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Pittsburgh
Williams and Co., Inc.
York
Southern Oxygen Co.
TENNESSEE
Kingsport
Southern Oxygen Co.
Knoxville
Southern Oxygen Co.
TEXAS
Dallas
Metal Goods Corp.
Houston
Metal Goods Corp.
UTAH
Salt Lake City
Pacific Metals Company, Ltd.
VIRGINIA
Arlington
Southern Oxygen Co.
Charlottesville
Southern Oxygen Co.
Lynchburg
Southern Oxygen Co.
Norfolk
Southern Oxygen Co.
Richmond
Southern Oxygen Co.
Roanoke
Southern Oxygen Co.
WASHINGTON
Seattle
Pacific Metal Co.
WEST VIRGINIA
Bluefield
Southern Oxygen Co.
WISCONSIN
Milwaukee
Machinery & Welder Corp.

cable sockets. These sockets will accept No. 2 through No. 3/0 aluminum or copper cable. A $^{7}/_{32}$-in. hex drive wrench reportedly tightens the screws with tremendous pressure. The burnishing action of the ball-point screw removes the oxides from the cable strands allowing a clean metal-to-metal contact. Each tiny strand is held under extreme pressure resulting in maximum conductivity. A heavy wall fibre sleeve covers the splice for maximum safety.

The manufacturer reports that its ability to stay tight and maintain its electrical efficiency has been proven by over two years of field use under severe working conditions.

For more details, circle No. 60 on Reader Information Card.

A-C, D-C Welders

The Miller Electric Mfg. Co., Inc., Appleton, Wis., announces the development of a new combination a-c,d-c welder for inert-gas and metallic-arc processes.

Designated the Miller Gold Star 300 Series, this machine in extensive field testing has "demonstrated a marked superiority over any electrically controlled welder ever before built," according to Miller engineers.

The electrical control circuit permits

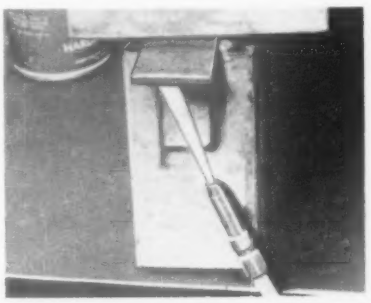
addition of a wide choice of timers and remote controls for manual and automatic metallic and inert-gas operation. . . .including inert-gas spot welding. The Gold Star 300 Series line of 16 machines stems from four basic models which offer a-c or d-c welding range amperages of 2–300, 3–425, 4–550 and 17–750.

Conversion kit, available as optional equipment, adapts the Gold Star 300 to any one of seven different processes—all from the one cabinet: a-c metallic arc; d-c metallic arc; a-c inert gas, manual; a-c inert gas, automatic; d-c inert gas, manual; d-c inert gas, automatic; and d-c inert gas, spot welder.

For more details, circle No. 61 on Reader Information Card.

Surfacing Spray Powders

A new line of hard-surfacing Hi-C spray powders has been developed by Western Carbide Corp., 6840 Vineland Ave., North Hollywood, Calif., for general industrial applications, including oil tool hydraulic equipment, farm tools,



earthmoving equipment, automotive and electrical uses. The new powders reportedly permit selection of the Rockwell C hardness required by ordering the proper number.

Service life of parts treated by Hi-C is said to extend even in environments of high temperature, abrasion or acids. According to the manufacturer, more than 80% of physical strength is retained at 1000° F, approximately 70% at 1400° F. Hi-C spray powders are nickel-base alloys and can be sprayed from various types of guns and applied to practically all metals with melting points above 1850° F.

For more details, circle No. 62 on Reader Information Card.

Bronze Welding Rod

The Weldrod Department of Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis., announces the availability of a new all-purpose, low-fuming, manganese-bronze filler rod known as Ampco-Braz # 2.

According to the manufacturer, Ampco-Braz # 2 finds exceptional service in brazing and braze-welding steel, cast iron, malleable iron, copper and copper-base alloys in addition to overlaying bearings and other wear—and corrosion-resistant surfaces.

Ampco-Braz # 2 is also said to provide smooth, dense, free-flowing deposits with excellent tinning action producing relatively high-strength joints up to 60,000 psi. Overlay deposit hardness is 80–110 BHN (500 kg).

Ampco-Braz # 2 conforms to AWS-ASTM designations: R Cu Zn C; B Cu Zn-A and Federal QQ-R-571a, Type 1, Class FS-R-Cu Zn 3, Amend. 1.

For more details, circle No. 63 on Reader Information Card.

Danny says:

"Airco's complete line of stainless steel electrodes eliminates guesswork"

Airco provides me with a stainless steel electrode with a deposit to match the base metal of any item to be welded. I don't guess — I select! The AC-DC coated electrode is the favorite with most operators. The arc action is smooth. The bead looks exceptionally good and slag is easy to remove.

Why not send for the free Airco Electrode Guide which will help you select the right electrode for your specific job. Request catalog 1318.

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A Division of
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Handling Equipment

Harper Steel & Supply, Inc., P. O. Box 33, Wichita, Kan., have introduced four different designs of all-welded handling trucks. The "Uni-Handle" series of cylinder trucks uses a new single column support for light weight, strength and low cost. This

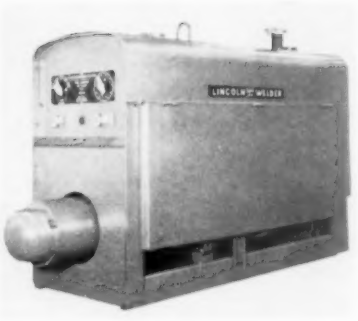
series handles small and medium cylinders. The continuous handle or dual handle design is used on the trucks handling the medium and large cylinders. The manufacturer states that six models of industrial hand trucks are available, handling loads from 300 to 800 lb with ease and safety. A truck in the Harper Line is the "Wheel'N Reel Truck" designed to move reels of welding cable, electrical wire, hose and wire line. The entire line of Harper Trucks is of all-welded design. Harper Trucks are distributed by welding supply distributors.

For free catalog and price list, circle No. 65 on Reader Information Card.

200-Amp Welder

The Lincoln Electric Co., Cleveland, Ohio, announces a new model of its 6090, 200-amp, gasoline engine-driven portable arc welder. The new welder, called the K-6090, is NEMA rated 200 amp at 40 v and 60% duty cycle, has dual controls for the generator output, an electrical outlet providing 1 kw of auxiliary d-c power, an idling device and is powered by a 36-hp water-cooled engine.

According to the manufacturer, controls on the new model K-6090 include a five-step selective current control and a continuous voltage control which also provides fine adjustments in the current. The ranges of the steps on the selective current control overlap, so that it is possible to obtain either a high



or a low open circuit voltage for any current, thereby selecting the type of arc most appropriate for the work. The auxiliary power is 115 volt, dc, which may be used for power tools or lighting. Welding controls, auxiliary power outlet, and wing-nut output terminals for the welding cable are externally mounted and readily accessible.

For more details, circle No. 66 on Reader Information Card.

Angular Torch Head

The new angular machine-torch adapter now being marketed by Air Reduction Sales Co., A Division of Air Reduction Co. Inc., 150 E. 42nd St., New York 17, N. Y., is adjustable through the wide range of 250°. Because of the versatility of the unit, it replaces their entire line of fixed angular heads.

According to the manufacturer, the cutting angle can be set without tools, and without removing the accessory from the torch. Any required angle can be set between 0 and 90 deg either side of vertical, and within an additional 35 deg above horizontal. Both sides of the body bear indexing marks in increments of 5 deg.

The angular head accommodates standard Airco acetylene, propane, and natural-gas tips, and is designed for service with the Airco Style 4700 machine cutting torch.

For more details, circle No. 67 on Reader Information Card.

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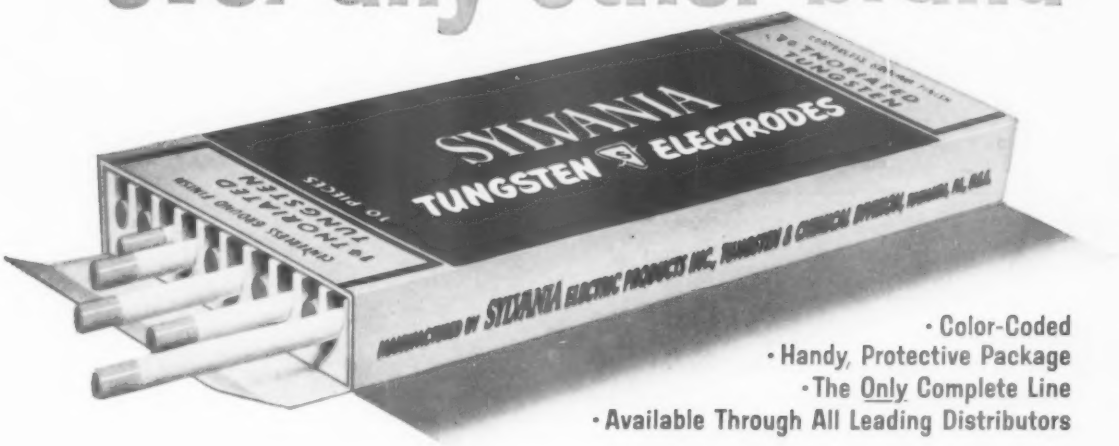

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For more details, circle No. 68 on Reader Information Card

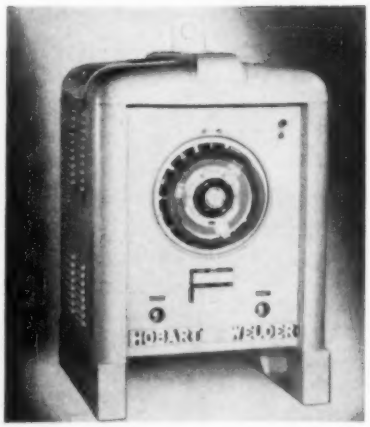
A-C Transformer

A new triple rated a-c transformer-type arc welder for operation on single phase, 60 cycles, 230-v input is announced by Hobart Brothers Co., Troy, Ohio.

Output of this new welder at 30 volts is 295 amp on 20% duty cycle, 250 amp on 30% duty cycle and 200 amp on 50% duty cycle. The transformer is the "Diverter Path" type with magnetic control for maximum efficiency, safety and silent operation.

According to the manufacturer, the controls provide five main steps of coarse adjustment (1-2-3-4-5) for use in all conventional a-c welding, as well as for certain inert-gas welding applications. Four additional steps are provided (A-B-C-D) for use in certain other inert-gas welding; also usable for conventional welding, but only with E-6013 type electrodes and only for downhand welding. A rheostat in the center of the 5 range wheel operates in each step to provide fine adjustment of the arc, making possible an infinite number of welding settings.

The welder is available with or without capacitors for power factor correction. The stationary unit is 32⅝ in. high, 21 in. wide, 21 in. deep and net



weight is 245 lb. Portable mounting is optional.

For more details, circle No. 70 on Reader Information Card.

Cable Plugs

A quick means for attaching whip cables to lead cables is provided with the new "Tweco whip cable plug" just announced by Tweco Products, Inc., Wichita, Kan.

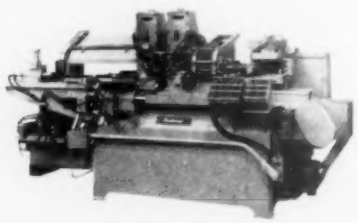
The new "whip cable plug" is used in combination with the BP-230 Tweco Cable Splicer. The "splicer" is attached to the lead cable by the use of the ball-point screw principle. The "whip cable plug" is attached to the

holder whip lead in the same manner. The two parts are connected by inserting the "whip cable plug" into the open end of the "cable splicer." They are held tightly together by the ball-point screw which is driven down into the concave hollow of the male plug by a few turns of the $\frac{7}{32}$-in. hex wrench. The male plug is split which allows the ball-point screw to wedge the male plug securely inside the female receptacle of the splicer. The manufacturer states that the large area of contact, plus the extreme pressure of the screw, results in maximum electrical efficiency between these parts. A three-quarter turn of the ball-point screw will release the "whip cable plug."

For more details, circle No. 71 on Reader Information Card.

Flash Welder

The Federal Machine & Welder Co., Warren, Ohio, announces a machine designed to resistance flash weld worms to ends of automotive steering gear shafts. Both parts are automatically fed from loading chutes, injected against



a gage bar for correct weld position, and ejected after welding. Marking device for shaft and radial positioner for worm are incorporated in the automatic sequence. According to the manufacturer, safety feature stops continuous machine operation if part loading chutes become empty. The welder incorporates a 150-kva transformer.

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National-U.S. Radiator Corporation

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Ultrasonic Testing

A portable, battery-operated ultrasonic thickness-measuring unit has recently been perfected by Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill. The Sonizon SO-200 locates

areas of corrosion or wear on storage tanks, pipes, ship hulls, airplane wing skins, drier rolls and other structures and products accessible from one side only. During manufacture, thickness can be measured, and laminations and lack of bond between materials can also be detected.

The manufacturer discloses that with a new means for reading ultrasonic-thickness measure, the SO-200 is fast, positive and simple to operate. In effect, it gives direct readings of thickness.

The SO-200 reportedly requires no warm-up time. It measures with an accuracy of ±3% on thicknesses between 0.027 and 4 in., and works on practically all materials which will transmit ultrasonic sound.

Other specifications are: unit weight, $3^1/_4$ lb size, 9 x 8 x 9 in.; battery case weight, $11^1/_2$ lb.

For more details, circle No. 80 on Reader Information Card.

Welding Engineer

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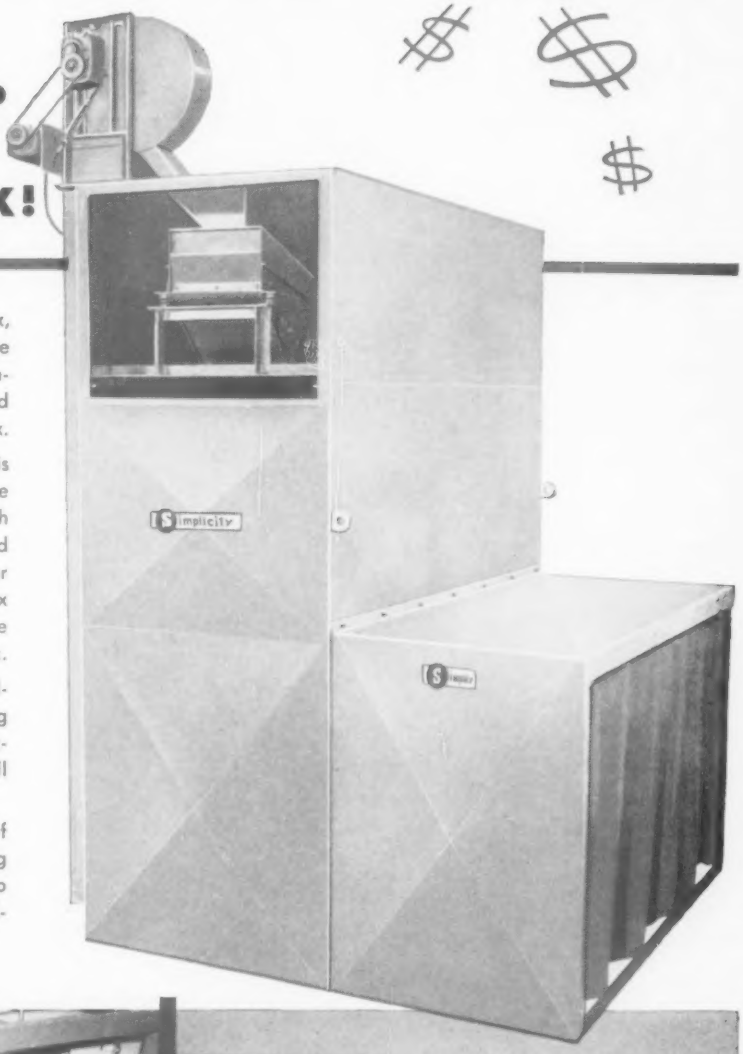

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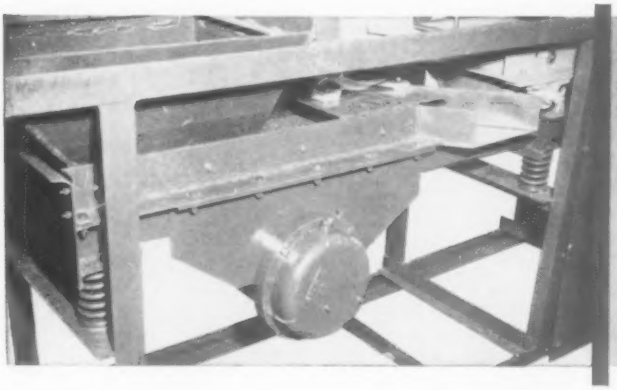

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DIFFUSION PHENOMENA IN PRESSURE WELDING

Weld interface in pressure-welded copper-brass specimens studied to determine the diffusion processes that occur during subsequent heating

BY A. G. GUY AND A. L. EISS

ABSTRACT. A study was made of the pressure welding of "sandwich" specimens and of the diffusion processes that occur during subsequent heating of these specimens. Conventional wire markers were unnecessary since impurity particles at the weld interfaces served this purpose. Sandwich specimens were made using several combinations of copper and brass, various surface preparations, welding pressures and welding temperatures. Several characteristics of the weld interfaces were studied such as width, straightness, and parallelism. Welded specimens were given diffusion heat treatments under various conditions to obtain information on the transport of zinc along the weld interface. "Extra" interfaces were observed in many of the specimens.

Introduction

The accuracy of data on diffusion in metals has in general been poorer than one would expect from a consideration of the laboratory manipulations involved. In the case of self-diffusion it has been recognized that systematic errors were the source of the lack of agreement among various investigators, and consistent values for the self-diffusion coefficient for silver have now been obtained by several laboratories. Diffusion in dilute substitutional solid solutions and in interstitial solid solutions can now be measured with sufficient accuracy to justify attempts at formulating a detailed theory of diffusion.[1]

The situation is not so satisfactory in those instances of diffusion in which a Kirkendall shift can be observed. The task of measuring diffusion coefficients is then complicated by such factors as sharp concentration gradients, plastic deformation and void formation, so it is not surprising that the agreement among various investigators is generally poor. In this laboratory an attempt is being made to find the possible systematic errors in this type of diffusion measurement. The present paper is a report on the weld interface, which plays a crucial role in the determination of the Kirkendall shift during a diffusion experiment.

Conventional "sandwich-type" specimens were used in the research. These consisted of a welded assembly of three disks, each made from one-inch diameter bar stock; the center disk (generally copper) was $^1/_4$ in. high, and the upper and lower disks (generally brass) were each $^5/_8$ in. high. The specimens are described more fully below, but it is important to consider first the nature of the two interfaces (copper to brass) in a typical sandwich specimen and the various methods of marking these interfaces.

A comprehensive study of the use of various markers was made by da Silva and Mehl.[2] Although the "foil method" that they recommended has not been generally adopted by other investigators, their procedure of using imbedded tungsten wire to mark the Kirkendall interface is widely employed.[3,4]

Many investigators, including da Silva and Mehl, had noted that adventitious impurities remained at the weld interface and so might perform the function of markers. In fact, Le Claire and Barnes,[5] in their discussion of the paper by da Silva and Mehl, presented a photomicrograph of a copper-nickel couple in which the original "unmarked" interface was revealed by electropolishing even though the specimen had undergone prolonged, high-temperature diffusion.

Since the impurity particles are very small compared to a wire marker, they increase the precision with which the interface can be measured. Also, they have the advantage of revealing the entire length of the interface, rather than merely isolated points along it. A further advantage in dispensing with wire markers is the increased precision that is possible in fabricating the sandwich specimen since the heavy loading to preset the wires can be eliminated.

A. G. Guy is professor of Metallurgical Engineering, School of Chemical and Metallurgical Engineering, associated with Purdue University, Lafayette, Ind. and **A. L. Eiss** is associated with Sylvania-Corning Nuclear Corporation, Bayside, Long Island, N. Y.; formerly Aluminum Company of America Fellow, School of Chemical and Metallurgical Engineering, Purdue University, Lafayette, Ind.

* This paper is based on a thesis by A. L. Eiss, submitted, in partial fulfillment of the degree of Master of Science in Metallurgical Engineering, to the Faculty of Purdue University.

This research was supported by the United States Air Force Office of Scientific Research of the Air Research and Development Command under Contract No. AF 18(600)1463.

Table 1—Analysis of Alloys

Alloy	Composition				
	Cu	*Pb*	*Fe*	*Ni*	*Zn*
OFHC copper	99.99	...	...	...	...
Electrolytic tough-pitch copper	99.9	...	...	...	...
80/20 brass	80.07	<0.005	<0.005	<0.005	balance
70/30 brass	69.7	<0.07	<0.05	...	balance

The disadvantage of relying on adventitious impurities to mark the interface has been their elusive nature. The usual experience in this regard was that the interface could be located relatively easily after welding, but in many specimens it would apparently have vanished after a diffusion treatment. Studies of specimen preparation, carried out on copper—α brass couples, demonstrated that the difficulty was largely one of appropriate metallographic technique. Diffused specimens were chosen that failed to reveal the weld interfaces both in the unetched condition and after ordinary etching with H_2O_2–NH_4OH solution or after electrolytic etching with an orthophosphoric acid solution. The interfaces on these specimens were easily revealed by electropolishing using a solution of 3 parts orthophosphoric acid and 5 parts water or by chemical polishing at 80° C using 1 part glacial acetic acid, 1 part orthophosphoric acid, and 2 parts nitric acid.[6]

Experimental Procedure and Results

The alpha copper-zinc alloys were chosen for this study because of the extensive previous work that had been done on this system. The analyses of the commercially extruded rod alloys that were used are given in Table 1. Generally the disks were annealed before being welded, but control experiments with the harder as-received material gave identical results. The types of welded sandwiches that were studied are listed in Table 2. The preparation and welding of the sandwiches will now be described.

Since it is desirable that an interface for diffusion measurements be plane and parallel to the companion interface, special care was exercised in the preparation of the surfaces of the copper and brass disks. Two characteristics of the surfaces were of special interest: (1) the flatness of each surface, and (2) the degree of parallelism of the two surfaces of each disk, especially the center disk.

It was found that a suitably flat surface could be obtained, without objectionable rounding at the edges, by mounting the disk to be polished in a special holder that had the effect of placing a protective edge around the specimen. This steel collet-type device is shown in Fig. 1. The mounted disk was hand-polished on metallographic papers of successively finer grit, Nos. 1 through 4/0. Examination of representative polished surfaces using an optical flat showed that the departure from flatness was about 0.00005 in.

Fig. 1 Special collet-type holder used in polishing copper and brass disks

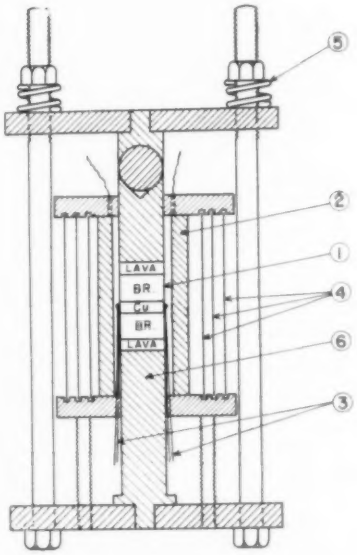
The best tolerance on parallelism of the opposite surfaces that it seemed feasible to achieve was ±0.0001-in. variation in height of a disk. This precision was easier to reach if the finish-machining operation had previously left the height constant to nearly this degree. Judicious mounting of the disk in the special holder could then result in a reduction in the variation in height during the polishing operation. The height of each disk was measured to ±0.0001 in. using a calibrated micrometer caliper. Also, after the disks were assembled in sandwich form a measurement was taken of the height of this assembly.

Two methods of surface preparation were employed as a preparation for welding; (1) mechanical polishing, and (2) mechanical polishing followed by etching. In the first method, which was used on the majority of the specimens, special precautions were observed in an effort to maintain uniform cleanliness of the surfaces. For example, the polishing of these surfaces was done only a few hours before welding, and the surfaces were cleaned with alcohol just before being assembled in the welding apparatus. In the second method the polished surface was etched for 5 sec by swabbing with cotton dipped in a solution of 1 part nitric acid and 3 parts water. Staining was prevented by immediate rinsing with hot water and drying in an air blast.

Welding was done in the special apparatus sketched in Fig. 2. The following features were stressed in the design and construction of this apparatus:

1. Axiality of loading of the specimen was assured by careful alignment of the various loading members. Also, the top member was adjusted on the three supporting rods so that it was accurately parallel to the base prior to the gradual application of the load. The load was applied through three calibrated springs and, at the end of an experiment, the final load could be determined by observing the tension remaining in the springs. In all of the runs tabulated here the load was essentially unchanged.

2. Satisfactory alignment of the three disks in a sandwich was attained by having the specimen exposed to view until after the load had been applied. A furnace was then assembled around the specimen. The furnace consisted of two split heating elements 4 in. high and 1¼ in. in diam, top and bottom Lava plates, and nickel-foil radia-



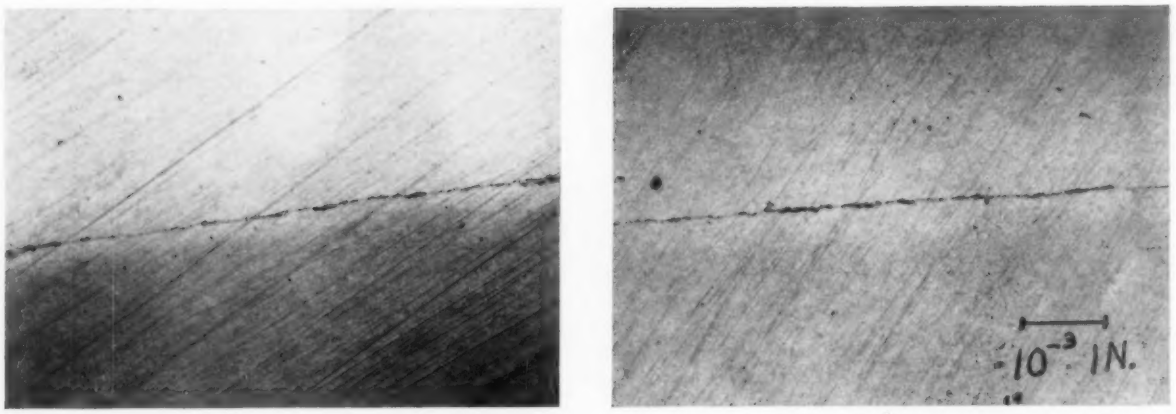
① WELD SPECIMEN
② ELECTRIC RESISTANCE HEATER
③ THERMOCOUPLES
④ NICKEL RADIATION SHIELDS
⑤ LOADING SPRING
⑥ INCONEL COLUMN

Fig. 2 Sketch of the apparatus used in welding the sandwich specimens

Table 2—Data on Welded Sandwich Specimens

Specimen No.	Type of sandwich*	Welding Conditions† Nominal welding temperature, °F	Welding pressure, psi	Height of copper disk before welding, in.	Separation of interfaces in welded sandwich, in. Position 1	Position 2	Total shift of interfaces, in. × 10^4	Departure of interface from straightness, in. × 10^4	Relative width of interface	Tensile strength, psi	Remarks
					Series with OFHC copper						
45	80/20|Cu|80/20	1350	15	These specimens broke at a weld interface during a cutting operation							
44	same	1350	70								
40	same	1350	160	0.2311	0.2312	0.2312	1	2.0	broad		
47	same	1450	15	0.2625	0.2627	0.2626	1	1.6	average		
48	same	1450	70	0.2412	0.2415	0.2413	2	1.2	average		
46	same	1450	160	0.2595	0.2598	0.2596	2	1.6	broad		
42	same	1550	15	0.2415	0.2419		4	1.6	average	2,500	
41	same	1550	70	0.2257	0.2262	0.2260	4	0.4	fine		
39	same	1550	160	0.2404	0.2406	0.2405	2	0.8	average	2,400	
51	same	1550	160	0.2599	0.2602	These specimens were used for the diffusion studies summarized in Table 3					Disk surfaces were oxidized before welding
53	same	1550	160	0.2520	0.2521						Unannealed disks were used
55	same	1550	160	0.2600	0.2604						Specimen was welded in vacuum
38	Cu|Cu|Cu	1550	160	0.2463	0.2464						
52	same	1550	15	0.2640	0.2641						
58	same	1550	200	0.2464	0.2465						
37	70/30|Cu|70/30	1550	160	0.2256	0.2264	0.2261	6	1.2	broad		
59	same	1600	130	0.2560	0.2569	These specimens were used for the diffusion studies summarized in Table 3					Surfaces were etched before welding
61	same	1600	130	0.2542	0.2550						
60	same	1600	130	0.2540	0.2548						
					Series with electrolytic tough-pitch copper						
34	70/30|Cu|70/30	1400	15	This specimen broke at a weld interface during a cutting operation							
31	same	1400	70	0.2531	0.2547	0.2549	17	0.4	average		
29	same	1400	175	0.2463	0.2473	0.2473	10	0.4	average	11,000	
30	same	1500	15	0.2402	0.2430	0.2433	30	0.8	broad		
26	same	1500	70	0.2430	0.2445	0.2446	16	0.4	average		
28	same	1500	175	0.2474	0.2481	0.2484	9	0.4	average		
27	same	1600	15	0.2486	0.2510	0.2513	26	0.4	average	6,000	
33	same	1600	70	0.2477	0.2492	0.2493	16	0.4	average	8,000	
32	same	1600	175	0.2412	0.2420	0.2421	9	0.4	average	10,000	
T1	Cu|Cu|Cu	1550	130	0.2502	0.2501	This specimen was used for the diffusion studies summarized in Table 3					Specimen was welded in vacuum

* 80/20 designates a brass containing 20% zinc. 70/30 designates a brass containing 30% zinc.
† Specimens were held at the welding temperature for one-half hour.



a b

Fig. 3 Photomicrographs of typical interfaces in welded sandwich specimens. (a) A fine interface in specimen 55; (b) an average interface in specimen 51. X 500. Unetched

tion shielding that was fed into spiral grooves in the Lava plates.

3. A good vacuum or an uncontaminated protective atmosphere was made possible through the use of furnace materials that could be easily outgassed. The nickel radiation shielding was far superior in this respect to conventional furnace insulation, and Lava was found to be suitable also for thermally insulating the sandwich from the members of the compression column.

The entire welding apparatus was placed under a cylindrical steel bell jar to permit operation in vacuum or in a protective atmosphere. Thermocouple wires for a temperature controller and for a measuring potentiometer were introduced into the bell jar by lead-through seals in the base on which the bell jar rested. To avoid disturbing the vacuum connections in these seals the wires passing through them were fastened permanently to two terminal blocks, one inside the bell jar and one outside. Thermocouple connections were then made at these terminal blocks. After a specimen had been mounted in the welding apparatus, a vacuum of about 50 microns was drawn and the furnace was heated to about 500° F for 10 min to outgas the system. During the latter part of this time, the system was flushed with dry, purified forming gas (10% hydrogen, 90% nitrogen) and re-evacuated to a vacuum of about 200 microns. The welding apparatus was then filled with forming gas at atmospheric pressure and heating of the furnace to the welding temperature was begun. The specimen reached welding temperature in somewhat less than 10 min, was held there for 30 min and cooled to about 400° F below the welding temperature within 5 min after the furnace was turned off.

Temperatures were controlled and measured using two calibrated chromel-alumel thermocouples positioned adjacent to the central copper disk. The welding temperature was held constant

Table 3—Results of Diffusion Treatments

Sample No.	*Type of sandwich*	*Diffusion temperature, °F*	*Diffusion time, hr*	*Shift of interfaces during diffusion, in. × 10^4*		*Character of interfaces*	*Remarks*
				Observed	Adjusted		
		Specimens diffused in vacuum					
T1-A	Cu|Cu|Cu (tough pitch)	1600	65	0	...	fine	
52	Cu|Cu|Cu (OFHC)	1600	65	2	...		
		Specimens diffused in a charcoal pack					
T1-B	Cu|Cu|Cu (tough pitch)	1605	65	68	...	opened	
38	Cu|Cu|Cu (OFHC)	1605	65	1	...	fine	
		Specimens diffused in an atmosphere rich in zinc vapor					
39	80/20|Cu|80/20	1600	65	40	41	fine	
51-A	same	1610	62	39	39	fine	
55	same	1610	62	32	32	fine	
52-B	Cu|Cu|Cu (OFHC)	1600	68	~120	~120	average	
58-A	same	1600	68	~60	~60	average	
59-B	70/30|Cu|70/30	1600	68	61	61	fine	
60-B	same	1600	68	66	66	fine	
61-B	same	1600	68	69	69	fine	
		Specimens diffused in an atmosphere poor in zinc vapor					
52-A	Cu|Cu|Cu (OFHC)	1630	68	52	47	opened	copper plated
51-B	80/20|Cu|80/20	1625	62	25	24	fine	
53-B	same	1630	68	54	48	fine	
53-A	same	1630	68	153	137	opened	copper plated
55†	same	1630	68	15	...	opened	copper plated
59-A	70/30|Cu|70/30	1630	68	67	60	fine	copper plated*
60-A	same	1630	68	83	74	broad	copper plated*
61-A	same	1630	68	76	68	fine	copper plated

* These two plated samples were heated for 4 hr at 500° F in a vacuum of 10 microns to remove hydrogen.
† After being given the treatment listed above, this sample was copper plated and given this second diffusion treatment.

within ±10° F. Blank runs made with a thermocouple inserted in a hole in a dummy specimen indicated that the specimen was roughly 50° F below the temperature read during the welding run. This correction has been applied to the temperatures shown in Table 2.

After the welding operation, a specimen was cut longitudinally to produce two or three samples. One of these samples was examined under the microscope to observe the results of the welding treatment and the others were used primarily for additional diffusion experiments. A few tensile-test specimens were also made. These consisted simply of a $\frac{1}{4}$-in. diam longitudinal section of a specimen; threads for gripping the specimen were cut in the two brass portions.

Table 2 presents the results obtained on representative as-welded samples. The degree of parallelism of the two weld interfaces was determined by measuring the separation of the interfaces at two positions 0.20 in. apart. The measuring microscope previously described[7] was used to obtain a precision of ±1 micron. Subtraction of the average of these values from the measured height of the copper disk before welding gave the observed total shift of the interfaces during welding. The typical local departures from straightness of an interface were determined by comparison with a hairline in the microscope ocular. The values recorded are the amplitudes of typical "waves" in an interface. The relative "width" of an interface was judged qualitatively in the unetched condition after polishing through 1 micron diamond dust. Micrographs of typical interfaces are shown in Fig. 3.

Samples cut from the welded sandwich specimens were heated at the diffusion temperature, about 1600° F, under the several different conditions described by the sub-headings in Table 3. Samples diffused in a charcoal pack were contained in a section of steel pipe capped at both ends. All of the remaining samples were sealed under a forepump vacuum in Vycor glass tubes. Two of the all-copper samples, T1-A and 52, were merely sealed in this manner. However, samples containing brass sections were not in a vacuum atmosphere in the sealed container at 1600° F since the zinc vaporized and tended to maintain a high partial pressure of zinc.

In an effort to observe the effect of this atmosphere of zinc vapor on the course of diffusion in the sandwich-type samples, diffusion treatments were made in which the partial pressure of zinc was maintained at a high level (by placing extra 70-30 brass chips in the Vycor tube), and other diffusion treatments were made in which the atmosphere was maintained impoverished in zinc vapor. The latter condition was attained by keeping the amount of brass in the diffusion specimens to a minimum and by placing copper chips in the Vycor tube to react with the zinc vapor. Also, many of the specimens were given a thick, adherent copper plating in the region of the two interfaces in an effort to prevent the penetration of zinc vapor along the interfaces.

The diffusion heat treatments were carried out in a tube furnace controlled to ±5° F. In preparing the diffused specimens for microscopic examination care was taken to remove the surface material that had been affected by inward diffusion from the exposed surfaces. The polishing operations included hand grinding on metallographic emery papers No. 1 through No. 3-0 and on 600 soft Microcut paper. Wheel polishing was done with 6 micron and 1 micron diamond dust. After the specimens were examined microscopically in the unetched condition they were etched using the standard electropolishing procedure[8] but only for a short time, 40 sec. The separation of the two interfaces was measured. Subtraction of the value for the as-welded specimen from this value gave the shift of the interfaces during diffusion, Table 3. The character of the interfaces was also noted.

Discussion of Welding Study

As background for a consideration of the results of the welding study, Table 2, it is desirable to recall the commonly used method for determining the interface shift during diffusion in a sandwich specimen.[9] The sandwich is welded, and the interface separation after welding is taken as the initial value. The final interface separation is determined after diffusion. The difference between the final and initial separation is the sum of the Kirkendall shifts for the two interfaces.

The results for the series of OFHC copper specimens in Table 2 show that appreciable shifting of the weld interfaces occurred during the welding process itself. This shifting was a result of diffusion during the time the specimen was at the welding temperature. It is generally accepted[2] that the interface shift, S, obeys the equation,

$$S = Kt^{1/2} \qquad (1)$$

where t is the time at the diffusion temperature and K is constant at a given temperature for a given type of diffusion couple, such as 70-30 brass joined to copper. This equation predicts, for example, that the Kirkendall shift during a 1-hr welding operation would be 10% of the total shift in a 100-hr diffusion treatment at the same temperature. Evidently this appreciable shift has been overlooked in the usual experimental procedure.

As a test of the validity of this conclusion, comparison was made of the shift observed during the welding of specimen 37 and that reported by da Silva and Mehl[2] for their specimen B20, which was of similar composition. Specimen 37 was welded for one-half hour and Specimen B20 was diffused for

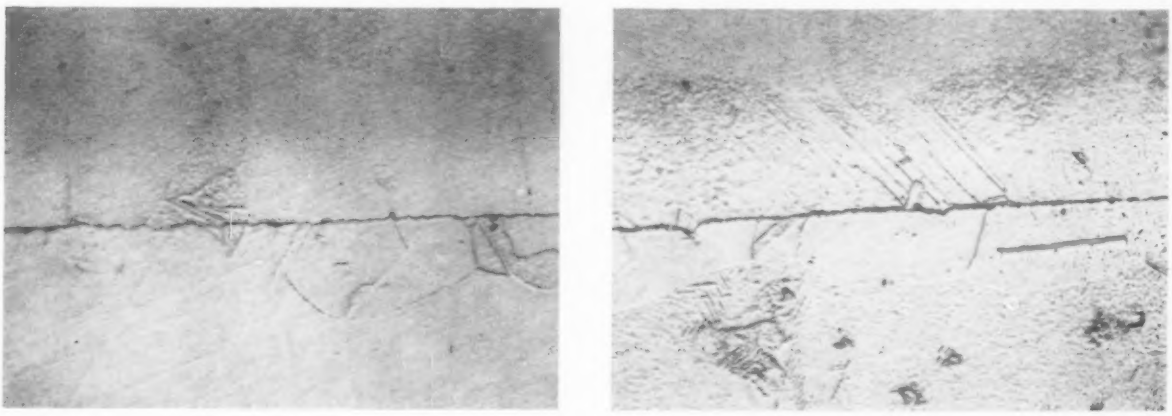


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Fig. 4 Photomicrographs showing the effect on a weld interface of etching before welding. (a) Specimen 61, etched; (b) Specimen 60, not etched. X 500. Microstructures etched with H_2O_2 — NH_4OH

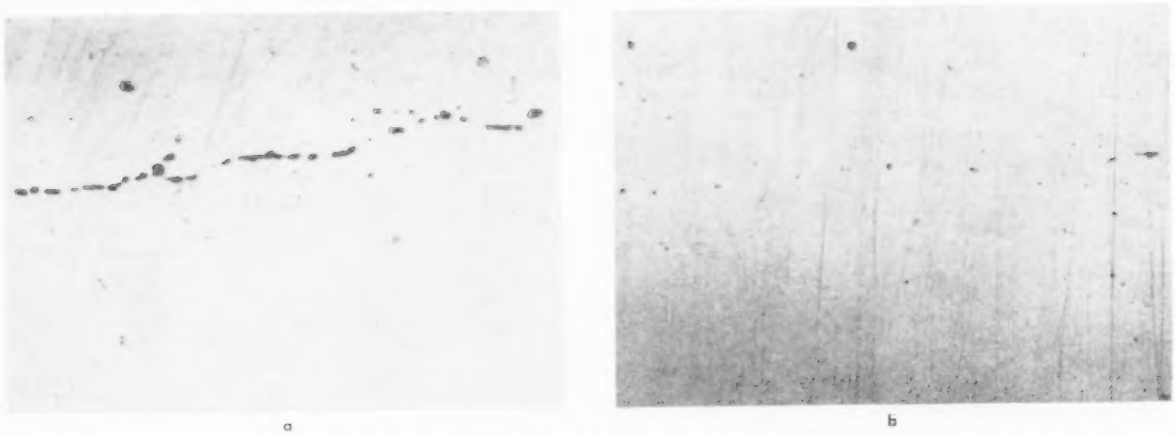

Fig. 5 Photomicrographs showing the effect on a weld interface of being "sealed off" by a copper plate during a diffusion treatment. (a) Sample 60-A, which had a poorer interface initially; (b) Sample 61-A, which had a better interface initially. X 500. Unetched

119 hr at about the same temperature. Equation (1) predicted that the Kirkendall shift in Specimen 37 would be 6.5% that in Specimen B20. The experimental value was 6%.

This error in measurement of Kirkendall shifts can be avoided if the following procedure is employed. The initial spacing of the interfaces is taken to be the height of the center (copper) disk, which is measured before welding. The final spacing of the interfaces is measured after the diffusion treatment. The observed shift is then associated with the total diffusion that occurred both during welding and during the diffusion heat treatment. This is the desired quantity in most instances.

A crucial question in regard to this procedure is whether the original height of the central disk is changed during the welding operation by influences unconnected with the Kirkendall shift itself. For example, if appreciable plastic deformation (creep) occurs during the welding process, the appropriate value for the "original height" will be less than that measured on the central disk. Or, if reactions occur inside the central disk during the welding treatment, significant contributions to the observed change in height may be produced in this way. In fact, it was shown that most of the "total shift" observed in the weld series with tough-pitch copper, Table 2, was caused by an internal reaction between the oxides in the copper and hydrogen in the protective atmosphere. This reaction was negligible in the OFHC copper disks.

To determine the importance of creep during the welding of copper and brass, specimens were made in which all three disks were of the same metal, Table 4. Since diffusion effects are essentially absent under these conditions, any shifting of the interfaces must be attributed to causes other than the Kirkendall effect. The data of Table 4 shows that the interface distances after welding were the same as the original height of the center disk within experimental error. Therefore, it was concluded that creep effects were negligible for the welding conditions employed.

Two properties of weld interfaces that bear on their usefulness for determining Kirkendall shifts are the parallelism of a pair of interfaces and the straightness of each interface. The data of Table 2 on separation of the weld interfaces show that departures from parallelism of as much as 0.0003 in. were observed over a distance of 0.2 inch. Since the original center disk had a degree of parallelism 10 times better than this, it is likely that the interface was disturbed by local variations in the rate of diffusion or in the character of plastic deformation. This view is supported by the data of Table 2 showing that the local departures from straightness of a weld interface were about 0.0001 in. even though the original polished surface had a finish 10 to 100 times smoother.

The strength of the welded specimens was adequate for such manipulations as light machining operations except for specimens welded at a combination of the lower temperatures and the lower pressures. The tensile-strength determinations were of only limited accuracy.

Discussion of Diffusion Studies

The first four samples in Table 3 were all-copper sandwiches of which Samples T1-A and T1-B were electrolytic tough-pitch copper while Samples 52 and 38 had center disks made of OFHC copper. It is seen that the OFHC copper was unaffected by the atmosphere in which the simulated diffusion treatment was carried out. The tough-pitch copper, however, was significantly changed by the reducing atmosphere of the charcoal pack.

To facilitate comparisons among the remaining samples in Table 3 it is convenient to adjust the observed values of interface shift to the same conditions of diffusion temperature and time. These were chosen as 1600° F and 68 hr. With the aid of the values of temperature dependence of the general diffusion coefficient, D, reported by Horne and Mehl,[9] the adjustment was made on the basis that the amount of Kirkendall shift is proportional to $(Dt)^{1/2}$, where t is the time.

The typical effect of the atmosphere in which the diffusion heat treatment was done is shown by Specimen 51. Sample 51-A, which was diffused in a zinc-rich atmosphere, experienced a

Table 4—Measurements of Creep in One-Metal Sandwich Specimens

Specimen No.	*Metal*	*Welding Conditions* Nominal temperature, ° F*	*Pressure, psi*	*Original height, in.*	*Interface distance after welding, in.*
38	OFHC Copper	1550	160	0.2463	0.2464
52	OFHC Copper	1550	15	0.2640	0.2641
54	80/20 Brass	1550	160	0.3018	0.3018
56	OFHC Copper	1550	15	0.2590	0.2591

* Specimens were held at the welding temperature for one-half hour.

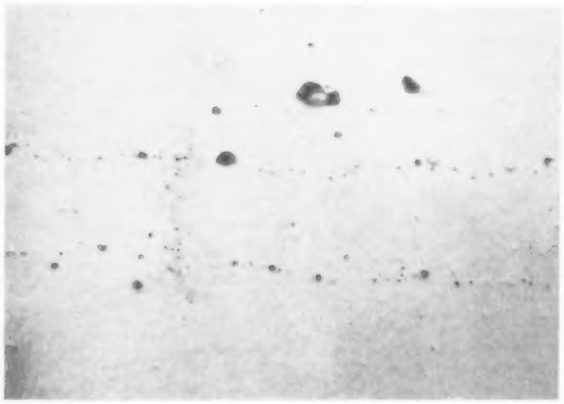

Fig. 6 Photomicrograph showing a typical "extra interface" (below) parallel to the Kirkendall interface; Sample 61-A. X 500. Electropolished

Fig. 7 Photomicrograph of a copper-copper interface in Sample 58-A along which zinc was transported. No trace of extra interfaces can be seen. X 500. Electropolished

larger interface shift, 39 x 10^{-4} in., than did Sample 51-B, which was diffused in a zinc-poor atmosphere. The shift of the latter was 24 × 10^{-4}. An obvious cause of this difference in shift would be the transport of zinc along the weld interfaces. The zinc could diffuse *into* Sample 51-A from the zinc-rich atmosphere and it could diffuse *out of* Sample 51-B into the zinc-poor atmosphere.

A convincing demonstration of the existence of such transport along weld interfaces was made using all-copper sandwich specimens, 52 and 58. The welding pressure was purposely kept low in making Specimen 52 so that it would have a poorer interface than Specimen 58. Consequently when Samples 52-B and 58-A were diffused in a zinc-rich atmosphere Sample 52-B showed an interface shift of about 120 × 10^{-4} in., while the value of Sample 58-A was only about 60 × 10^{-4}. There was no doubt that the cause of the shift was transport of zinc along the weld interfaces and hence into the copper since there was a brass color on both sides of each interface. In some specimens the zone of brass color was of uniform thickness at all depths below the specimen surface. However, in other specimens there was evidence that regions of excellent weld could retard the penetration of zinc.

Sample 52-A was a second sample of the sandwich with the poor weld interface. It was copper plated in the region of the two interfaces in an effort to impede the access of zinc vapor to the interfaces. Also, the diffusion treatment was carried out in a zinc-poor atmosphere. Although these measures did not prevent the access of some zinc to the weld interface, the interface shift was now only 47 × 10^{-4} in., about one-third that in Sample 52-B.

A peculiar effect was noticed in some diffused specimens that had been copper plated over the interfaces prior to diffusion. The interface would "open up" into a crack as much as 0.001 in. wide in some instances. The history of specimen 55 is especially striking. This specimen, Table 2, had good ("fine") interfaces as welded, Fig. 3*a*. Its reaction to the first diffusion treatment, Table 3, was typical in that its interfaces became even better, as judged by their appearance under the microscope. Next, the diffused specimen was given a copper plating to "seal off" the interfaces. It was then given a second diffusion treatment in a zinc-poor atmosphere. Microscopic examination after this treatment revealed that both interfaces opened up and were about 8 × 10^{-4} in. wide.

Several observations of this phenomenon suggested that the cause might lie in the imperfection of the interfaces themselves or that it might merely be an effect of hydrogen absorbed by the metal during the copper-plating operation. Specimens 59, 60 and 61 were made and tested to investigate these possibilities. In an effort to improve the perfection of the weld interfaces, the disks of 59 and 61 were etched as described above prior to welding. Microscopic examination, Fig. 4, showed that etching did produce a finer interface. Samples of all three specimens, 59-A, 60-A, and 61-A, were copper plated, and following the plating a heat treatment at 500° F in vacuum was given Specimens 59-A and 60-A to remove hydrogen introduced during plating. After all three specimens had been diffused in an atmosphere poor in zinc vapor their interfaces had the appearance shown in Fig. 5. That is, the sample with the poorer interface, 60-A had experienced a further broadening of the interface even though a degassing treatment had been used. On the other hand the samples with the better interfaces, including 61-A that had not received a degassing treatment, had extremely fine interfaces after the diffusion treatment. Therefore, it was concluded that the "opening up" of the interfaces under these conditions was somehow connected with imperfection of the interfaces.

Another interesting feature observed in many diffused samples, and even in some as-welded specimens, was the presence of "extra interfaces." A typical example is shown in Fig. 6 for sample 61-A. The upper interface is presumably the ordinary Kirkendall interface since it coincided with the join between the copper and brass disks at the edge of the specimen. The lower interface was towards the copper and in this sample was 12 × 10^{-4} in. from the Kirkendall interface.

A possible explanation of these extra interfaces is that they are small particles, initially at the joined surfaces of the two disks, that have become "buried" during the diffusion process.[10] This theory is supported by the observation of two extra interfaces, one on either side of the original weld interface, in Sample 52-B, an all-copper sandwich in which zinc had diffused along the weld interface. On the other hand, careful metallographic examination failed to reveal extra interfaces in Specimen 58-A, Fig. 7, a specimen similar to 52-B but with a better interface as welded. Also, a given specimen might show greatly different distances between the extra interface and the weld interface at its two interfaces even though the amount of over-all diffusion was about the same at the two interfaces. Thus, some factor in addition to the flux of zinc appears to be involved.

Conclusions

This study of the weld interface in pressure-welded copper-brass specimens has led to the following conclusions:

1. It is possible to refer the Kirkendall shift to the height of the center member of a "sandwich" specimen.

This procedure is more accurate and is more convenient experimentally.

2. Two techniques were found for judging the degree of perfection of a weld interface, in addition to microscopic examination: (a) observation of the tendency of the interface to "open up" during a diffusion treatment in which it is sealed off by a copper plate; (b) observation of the penetration of a volatile substance (zinc vapor) along the weld interface.

3. Light etchings of the surfaces to be welded significantly improves the perfection of the weld.

4. Transport of a volatile substance can occur along a weld interface either into or out of the specimen.

5. "Extra interfaces," which are often almost identical with the usual Kirkendall interfaces, occur in many specimens

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WELDING HIGH-TENSILE STEELS

BY K. L. ZEYEN AND H. SCHWARZ

Weldability today has lost its old meaning of ability to produce a weld free from defects. Instead it has come to mean freedom from hardening and brittle fracture. The St52 type of steel was the first step in developing steels satisfying the new definition. St52 with low carbon content replaced St48 with 0.30% C and the silicon-structural steels. Steels of St52 type developed in various countries are listed in Table 1. Usually these steels were fine grained, which suppressed brittleness. The HSB steels, Table 2, were fine-grained steels with 0.20% carbon maximum made by Phenix-Rheinrohr Co. in Mulheim in the Ruhr. These steels were very insensitive to welding because transformation occurred far above the martensite temperature.

The good notch-impact properties of the U. S. Steel Co.'s T-1 steel have been confirmed by the Escher Wyss Co. Their tests showed that good properties were exhibited in the as-received condition, after stress relieving, and after aging. However, normalizing destroyed the desirable heat-treated structure of the steel.

For several years, the Oerlikon Electrode Co. has used the Schnadt test to evaluate the plasticity of steels and weld metal. This test demonstrates the tendency of a steel to behave in a brittle manner under multiaxial tensile stress. A dimensionless quantity π which can vary from zero to two expresses the degree of multiaxiality which a steel can withstand without losing its plasticity completely. The Schnadt notch-impact specimens are so designed that the 3 × 10-mm. cross section is in tension only, not in compression. As the notch radius is reduced, the degree of multiaxiality increases. The Venant coefficient, $100\ V/(V + 1)$ where V = notch radius in millimeters varies from 0 where $V = 0$ to 100 where $V = \infty$, Table 3. A steel having only a low impact value, such as 2 mkg/cm², in the K_{10} specimen is unsuitable for structural service at the temperature of the test. On the other hand, a steel having over 8 mkg/cm² in the K_0 specimen is absolutely free from brittleness. The effect of welding is studied by means of six specimens cut from a bead on plate:

Specimen KSA	100 notch radius = ∞	heat-affected zone occupies the entire 3 mm
Specimen KSA	33 notch radius = 0.5 mm	heat-affected zone occupies the entire 3 mm
Specimen KSA	0 notch radius = 0	heat-affected zone occupies the entire 3 mm
Specimen KSZ	100 notch radius = ∞	Ac_1 zone of weld outside the specimen
Specimen KSZ	33 notch radius = 0.5 mm	root of notch on Ac_1 line of bead
Specimen KSZ	0 notch radius = 0	root of notch on Ac_1 line of bead

Abstract by **Gerard E. Claussen** of "Das Schweissen von Baustahlen mit Hoher Festigkeit," published in *Technische Rundschau* (Bern, Switzerland) No. 1/2 Jan. 11, 1957.

Dr. Claussen is associated with the Development Laboratories, Linde Co., Newark, N. J.

Table 1—Steels of the St52 Type

Country	Name of steel	Yield strength, psi	Tensile strength, psi	Maximum C	Maximum Si	Maximum Mn	Maximum P	Average percentage of Cr	Average percentage of Cu	Average percentage of Ni	Average percentage of Mo	Carbon equivalent in % at maximum alloy content
Germany	St52	49,800	74,000-91,000	0.20	0.60 (0.80)	1.6 (1.2)	0.05					0.43
England	DWDucol 24	54,000	78,200-92,500	0.21	0.30	1.5	0.06	0.25		0.5	0.15	0.53
	Balley	52,600	78,200-96,700	0.26	0.30	1.3-1.7	0.06					0.51
France	Ae54	49,800	74,000-91,000	0.22	0.30	1.2	0.04	0.40	0.6			0.51
Russia	Cx(?)	49,800	74,000-91,000	0.22	0.48	0.8	0.05	0.70	0.7	0.5	0.10	0.54
USA	MnNiCu	49,800	69,700-85,300	0.15	0.25	1.0-1.4	0.05		0.5-1.0	0.5-1.0	0.10	0.50
	Corten and Mayari	49,800	69,700-85,300	0.12	0.75	0.5	0.15	0.50-1.25	0.3-0.5	<0.65		0.44
	Aldecor	49,800	69,700-85,300	0.12	0.75	0.4	0.15		0.3-0.6		0.20	0.27

Table 2—The HSB Steels

Name	C	Si	Mn	Cu	Ni	Mo	Nitride or carbide former	Tensile strength, psi	Yield strength, psi: 3/4 in.	1 3/16 in.	2 in.	2 3/4 in.
HSB40	0.18	0.25	0.60				Al	57-64,000	41,300	39,800	38,400	37,000
HSB45	0.18	0.35	0.80				Al	64-78,000	45,500	44,100	42,700	41,300
HSB50	0.20	0.45	1.10				Al	71-85,000	51,200	49,800	48,400	46,900
HSB51	0.20	0.45	1.10				Al, Ti	73-88,000	55,500	54,100	51,200	48,400
HSB55	0.20	0.45	0.90	1.10	1.06	0.20	Al, Mo	78-97,000	65,400	64,000	62,600	61,200

Table 3—Coefficients of the Schnadt Specimens

Radius notch, mm	Venant value	Name of specimen	Name at test temperature T	π
0	0	K_0 (coheracy)	$K_0 + T$	0.433
0.11	10	K_{10}	$K_{10} + T$	
0.25	20	K_{20}	$K_{20} + T$	
0.5	33	K_{33}	$K_{33} + T$	
1	50	K_{50}	$K_{50} + T$	
2	67	K_{67}	$K_{67} + T$	
4	80	K_{80}	$K_{80} + T$	
∞	100	K_{100} (binacity)	$K_{100} + T$	0.866

Table 4—T-1 Steel

Composition

C	0.15	(0.15)	V	0.04	(0.05)
Mn	0.90	(0.75)	Cu	0.25	(0.31)
Si	0.29	(0.24)	S	0.016	(0.030)
Metallic Al	0.08		P	0.015	(0.026)
Cr	0.42	(0.50)	N	0.002	
Ni	1.09	(0.85)	B	Not determined	(0.0028)
Mo	0.42	(0.45)			

Mechanical properties

	Longitudinal	Transverse	
Yield strength, psi	113,800	113,800	(89,600)
Tensile strength, psi	122,300	122,300	(105,300)
Elongation, % in 5 diam	14	14	(18 in 2 in.)
Reduction of area, %	57	55	(55)

Charpy V-Notch-impact value, ft-lb

68° F: 48 ft-lb −40° F: 35 ft-lb
32° F: 51 ft-lb −76° F: 22 ft-lb
−4° F: 43 ft-lb

The first three specimens involve the entire heat-affected zone, while in the last three only the outer zone of heat effect is in the specimen.

The Reeve test for weld cracking is excellent and is embodied in Swiss Standard 14052. However, it has been found easy to pass electrodes with this test, which crack in the field. The Fisco crack test devised by H. M. Schnadt is a further development. Each plate is held in a press under 30 tons pressure during welding and cooling. A lateral pressure of 6 tons holds the plates together. The results of hundreds of these tests will be published soon.

The remainder of this article deals with tests to evaluate electrodes for welding T-1 and Aldur 50/65 steels each 0.79 in. thick. The properties of the steels are given in Tables 4 and 5, values in parentheses being manufacturers' values. Welds were made in all positions with a low-carbon, low-alloy, low-hydrogen electrode, Table 6. The results of tensile tests on butt welds in 0.79-in. plate are given in Table 7. The reinforcement was removed and the welds were tested as welded. The mandrel in the root and face bend tests was 3 1/2 in. diam, and all specimens bent 180° without fracture.

The results of notch-impact tests are given in Table 8. The plates were rigidly restrained during the welding

Table 5—Aldur 50/65 Steel

Composition

C	0.21	(0.19)	Mo	0.01	
Mn	1.30	(1.45)	V	...	
Si	0.43	(0.43)	Cu	0.10	
Metallic Al	0.07		S	0.036	(0.035)
Cr	...		P	0.023	(0.018)
Ni	0.27		N	0.011	

Mechanical properties

	Longitudinal	*Transverse*	
Yield strength, psi	82,500	81,000	(75,500)
Tensile strength, psi	101,000	104,000	(97,500)
Elongation, % in 5 diam	22	18	(15)
Reduction of area, %	62	52	(42)

Charpy V-notch-impact value, ft-lb	Swiss standard aged specimen, mkg/cm²
32° F 58	68° F (5.2)
−4° F 65	−4° F (3.8)
−22° F 60	−76° F (2.6)
−40° F 45	
−58° F 33	
−76° F 24	

Table 6—Average Properties of Weld Metal Deposited by Tenacito 70 Electrode

	*Treatment A**	*Stress relieved 5 hr at 1112° F*	*Normalized ½ hr at 1688° F*
Yield strength, psi	85,500	91,000	51,000
Tensile strength, psi	102,000	102,000	84,500
Elongation, % in 5 diam	21.4	21.1	25.2
Reduction of area, %	71.5	68.5	67.8
Charpy V, ft-lb	58†	62	
Schnadt Ko, mkg/cm²	9.0†	8.1	

* Treatment A involved heating 8 hr at 482° F to remove hydrogen.
† As-welded, without treatment A.

Table 8—Notch-Impact Results, Averages of Four Specimens

Welds were made with Tenacito 70 Electrodes

Test temperature, °F	*—Charpy V-Specimen, ft lb—*				*——Schnadt K_0 specimen, mkg/cm²——*			
	——T-1——		*Aldur 50/65*		*——T-1——*		*Aldur 50/65*	
	Plate	*Weld*	*Plate*	*Weld*	*Plate*	*Weld*	*Plate*	*Weld*
+68	48	52	...	65	6.8	9.3	8.7	8.8
+32	51	45	58	54	7.8	8.2	7.4	6.3
+14	...	...	...	...	6.6	...	...	...
−4	43	33	65	40	3.3	5.8	7.8	4.3
−22	...	...	58	...	2.7	...	7.3	...
−40	35	20	45	28	2.5	3.6	2.5	2.2
−58	...	16	33	25	...	2.6	...	1.8
−76	22	...	24	...	...	...	...	...

Table 9—Schnadt Impact Tests at +32° F of Unwelded and As-Welded T-1 and Aldur 50/65 Steels. Averages of 4 Specimens, mkg/cm²

Location of specimen	*Longitudinal*				*Transverse*			
Notch radius, mm	0.5	0.25	0.11	0	0.5	0.25	0.11	0
T-1, unwelded *	9.4	8.6	8.0	7.8	5.8	5.7	5.9	6.6
T-1 KSA specimen †	9.3	8.5	8.0	7.8	8.3	7.5	6.4	6.0
T-1 KSZ specimen ‡	9.5	8.5	8.0	7.8	8.4	7.7	6.5	6.3
Aldur, unwelded §	10.5	9.5	8.6	7.4	6.7	6.0	5.4	5.4
Aldur KSA specimen ‖	10.5	9.5	8.6	7.4	7.1	5.4	5.0	3.4
Aldur KSZ specimen ¶	10.0	9.6	8.5	7.5	9.9	9.5	8.3	7.5

* 214–231 Vickers hardness.
† 383–388 Vickers hardness.
‡ 201–230 Vickers hardness.
§ 242–274 Vickers hardness.
‖ 383–405 Vickers hardness.
¶ 239–251 Vickers hardness.

Table 7—Transverse Tensile Tests of Butt Welds

	T-1 steel	*Aldur 50/65 steel*
Yield strength, psi	97,500	77,000
Tensile strength, psi	117,000	102,000
Location of fracture	In weld	In plate at junction with weld

of these single-vee-butt joints. The interpass temperature was 212° F max. The temperature at which brittle behavior was exhibited was well below 32° F, so that both steels are absolutely safe against brittle fracture in any kind of service. The heat-affected zone of the T-1 steel was found to have a martensitic structure, while in Aldur 50/65 the structure was bainitic. The low-carbon martensite of T-1 steel is relatively soft and very tough.

Further tests were made with Schnadt specimens of four different notch radii using the KSA and KSZ heat-affected zone specimens, Table 9. Despite the high hardness of the heat-affected zone in T-1 steel, the impact values are remarkably high. The heat-affected zone of the Aldur steel was not so tough as the T-1 steel.

The Fisco cracking test was applied to the two steels using two electrodes: Tenacito 70 (0.07 C, 1.10 Mn, 0.10 Si, with low Cr, Ni, and Mo) and ZH704 (0.06 C, 0.82 Mn, 0.23 Si, 3.8 Ni, 0.66 Mo). With Tenacito 70 cracking was 12% of the bead length in T-1 and 15% in Aldur. The cracks were confined to the crater. With ZH704 all beads were 100% cracked.

All in all, the tests show that Tenacito 70 is suitable for welding both T-1 and Aldur 50/65 steels.

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VACUUM-METALLURGICAL RESEARCH GIVES INDUSTRY A GLIMPSE INTO THE FUTURE

Author presents some of the problems which have been solved by vacuum-metallurgical methods and discusses several others for which vacuum techniques appear to have particular potential

BY R. C. BERTOSSA

ABSTRACT. Recent progress in vacuum-metallurgical research allows increased latitude in designing new process equipment for the chemical, petroleum, paper-pulp and aircraft industries. Wider knowledge of new industrial applications of vacuum metallurgy and a realization of the potential of these promising techniques for future industrial development in advanced fields may be instrumental in bringing out new applications for this versatile process, and may assist in the solution of additional problems in the use of metals and alloys. The development of new potential applications could be instrumental in directing and encouraging further vacuum-metallurgical research along lines of greatest interest to industry.

Introduction

Techniques for production of metal alloys and for joining metals by brazing have been well known to industry for many years. These methods provided adequate alloys and satisfactory metal-to-metal joints over relatively small areas, using fluxes and/or gaseous atmospheres to minimize oxidation so that bonds could be effected.

Just prior to and during World War II, more highly alloyed metals, such as stainless steels, high-nickel alloys and others, became increasingly important for corrosion-resistance applications and for other newly conceived uses for which ordinary steels would not suffice. Attention was then turned toward higher temperature cobalt-base, nickel-titanium and other so-called "superalloys" to satisfy even more stringent metals applications.

This new interest sparked further growth of the alloying industry, although at that time many metals still resisted all attempts to produce ductile, uncontaminated alloys by commercial methods.

During this same period, developments in joining metals by brazing received little impetus through new applications, and apparently few people in the engineering profession could foresee any remarkable future in metals technology for what was commonly known as the "age-old art of brazing." Applications for brazing were relegated almost entirely to joining small ferrous or nonferrous metal parts where high strengths and uniform joint integrity were not always primary factors. Mass high-strength joining of heavy metal plates on the order of 100 to 1500 sq ft or more in area by integral and continuous flux-free, vacuum-brazed bonds; or commercial production of vacuum-melted, high-temperature alloys of such metals as titanium, zirconium, tantalum, columbium (niobium), molybdenum and many others, was considered impractical owing to the many serious problems involved. Many of the high-temperature metals were extremely sensitive to atmospheric gases at elevated temperatures and even some of the common reducing atmospheres were unsatisfactory. In brazing, the difficulties of flux removal from the bonding interface over large areas and the achievement of the required uniformly distributed high pressures over these areas were in themselves enough to discourage high-strength brazing on this scale.

About this time, metals fabricators began to experience increased difficulties in keeping pace with new developments in design for processing and industrial equipment. For example, development of highly corrosive by-products in the petroleum industry, where new and more efficient techniques of refining had been developed, made the problem of containment many times more acute than before.

The metals-fabricating picture was further complicated by new demands from engineers in the aircraft, missile, and atomic-energy fields for alloys and materials capable of withstanding service temperatures, corrosive environments, and other conditions far in excess of any previous specifications.

Expansion of Research on Unusual Metals

To satisfy the new demands, metallurgical research groups began to turn their attention more and more toward the development of commercial production and fabrication techniques for some of the more unusual metals. Many of these so-called unusual metals were in this category not because of their lack of abundance in nature, but because of the difficulties of extracting them from their ores, coupled with difficulties in forming, heat treating, and joining.

Metals such as titanium, zirconium, tantalum, columbium and molybdenum all have exceptional properties which made them desirable for use in newly developed processes and industrial equipment where requirements are too severe for ordinary metals and alloys.

Titanium has excellent corrosion resistance in the presence of chlorides, the lack of which has always been the "Achilles heel" of stainless steels. Titanium also has an excellent strength-to-weight ratio, which has resulted in its increased use in the aircraft industry.

Zirconium possesses extremely low "cross section," which means it has very low neutron-absorption characteristics, making it a desirable material for certain atomic-energy applications.

Tantalum, columbium and molybdenum all have excellent strengths at temperatures above 2000° F and very high corrosion resistance in certain environments, thus placing these metals and their alloys in heavy demand for high-temperature and high-corrosion applications.

Without exception, however, these metals have one common undesirable characteristic which makes them extremely difficult to produce, heat treat, and fabricate. They are easily embrittled at elevated temperatures by contact with even small quantities of atmospheric gases, such as oxygen, nitrogen, and hydrogen. In addition,

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they suffer very rapid deterioration through oxidation at elevated temperatures. This characteristic prevents their use in temperature ranges above those in which some common metals will suffice, even though their strengths are adequate for use, in some cases, up to 3000° F and above. For these reasons, these metals have not yet been exploited fully in the high-temperature field.

This is a field where considerable research is yet to be done, and where the characteristics of the metals involved are such that producing, heat treating, and joining them must be done under a very high degree of protection for atmospheric conditions.

Vacuum-Metallurgical Approach

The foregoing brief review of some major properties and characteristics of usual metals clearly indicates that special techniques are required if industry is to utilize the full benefits of their exceptional properties.

Since contamination by atmospheric gases and deterioration through oxidation at elevated temperatures appear to be major factors to contend with, what better control can be exercised in handling these metals and their alloys at elevated temperatures than to remove the source of the difficulties?

The use of vacuum-melting, heat treating and joining, therefore, is the direct approach to the problem, not only for the purpose of protection against contaminating gases, but also for removal of gases and other impurities from metals previously contaminated. This characteristic of vacuum metallurgy is termed "out-gassing," Table 1.

Table 1—Out-gassing Temperatures for Some Metals in Vacuum Less Than 1 X10^{-3} mm Hg

Metal	*Out-gassing temperature (max), ° F*
Copper and Cu Alloys	932
Iron	1832
Nickel and Ni alloys	1382–1742
Tungsten	3272
Molybdenum	3200
Tantalum	2552
Platinum	1832

The following characteristics and advantages of vacuum-metallurgical techniques illustrate how well suited they are for handling high-temperature metals:

1. High vacuum effectively excludes atmospheric gases during the entire time the metal is at elevated temperatures.

2. It can actually break down and remove oxide films previously built up on certain metals, cleaning and deoxidizing the surfaces of the metals.

3. Many nonmetallic, some metallic and some gaseous impurities are scavenged from metals, both upon vacuum melting and upon heating under vacuum without melting.

4. In brazing of metals, vacuum techniques exclude oxidation from the interfaces, allowing uniform and complete bonding without fluxes. Vacuum can be used also to exert very high uniform pressures on the bonding interfaces, bringing them into intimate contact, and thus insuring a uniform cross section of bond and highest joint strength with a minimum of brazing alloy.

5. In all operations, vacuum methods produce products which are bright and clean, and in many cases, need no further finishing prior to marketing.

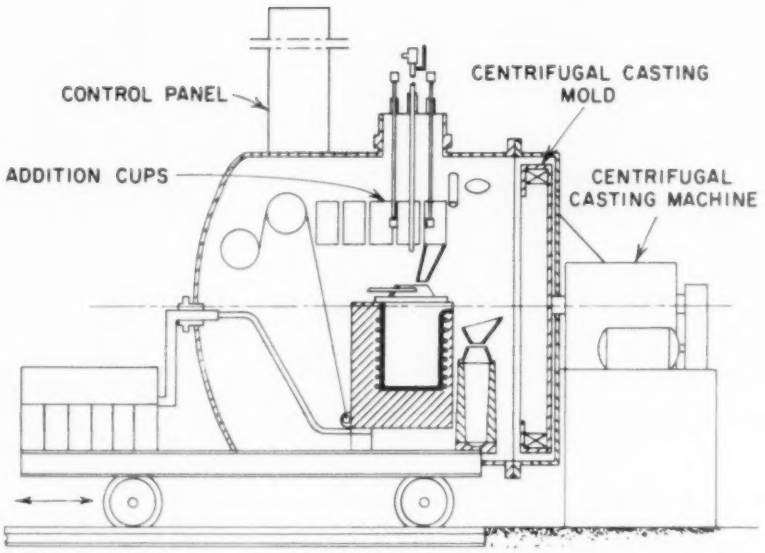

Fig. 1 Sketch of cross section of 1000-lb high-vacuum furnace in closed position

On the other side of the ledger, handling problems in vacuum-metallurgical work are somewhat complicated, equipment is intricate, and skilled, meticulous operators are required to produce, heat treat, join and decontaminate the metals. These particular problems are tangible, however, and are being resolved rapidly. Many commercial vacuum-melting, heat-treating and joining units are now in successful operation (Fig. 1) and it can be said safely that the technique is now becoming an important modern industrial tool.

The development of the full potential of vacuum-metallurgical techniques is far from accomplished at this time, and, as new applications are found and as research continues on applying vacuum techniques to many problems, the vacuum scientist envisions a remarkable future for this versatile product of the laboratories. Although it is estimated that many years of highly productive research lie ahead in developing applications for this relatively new technique, considerable progress has been made already and many difficult industrial problems have been solved, are being solved, or are in advanced stages of solution. To illustrate actual industrial problems which already have been solved and to give some insight into the future in store for vacuum metallurgy, progress made to date in solving some difficult and interesting problems will be discussed.

Recent Applications of Vacuum Metallurgy to Industrial Problems

Chemical Industry

In the chemical industry, advanced process designs called for process and containment vessels to withstand variations between high positive pressures and partial vacuums at elevated temperatures. The chemicals involved were extremely corrosive and could be contained only by certain noble metals such as silver, gold or platinum. Obviously, these metals could not be used to construct 20- to 30-ft vessels whose operating pressures required wall thicknesses equivalent in strength to 1 to 2 in. of steel. The solution appeared to be a continuously bonded, high-strength clad layer of noble metal on less expensive backing materials such as carbon or stainless steels. Discontinuously bonded noble metal liners had been tried and proved unsatisfactory in that heat and pressure variations while the vessels were "on stream" caused failures in the noble metal liner, which in turn allowed highly corrosive liquids to contact the backing steels. Failure resulted in a matter of days.

This particular problem was solved through the application of high-vacuum

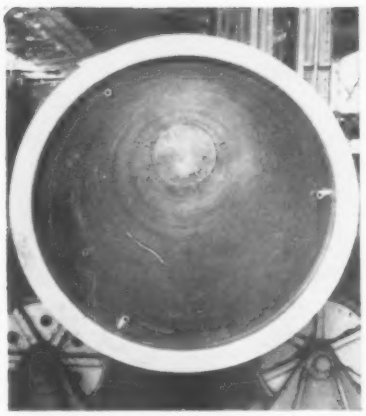

Fig. 2 Inside view of 3-ft diam by 20-ft vacuum-clad pressure vessel; $^1/_{16}$-in. fine silver integrally and continuously bonded to 1 in. of Type 316-L stainless steel

brazing. An initial experimental vessel over 20 ft in length, with $^1/_{16}$ in. of fine silver integrally and continuously vacuum bonded to 1 in. of austenitic stainless steel was produced (Fig. 2). The technique used was an adaptation of a unique vacuum-pressure cladding process for producing high-strength clad plates for subsequent fabrication into pressure vessels.

This process is, in essence, a method of cladding one or more metals on another similar or dissimilar metal, using selectively applied high vacuum at the bonding interface during the entire bonding and heat-treating cycle. This eliminates the need for a contaminating flux to effect bonding, and, in addition, provides a uniformly high pressure on the order of 15 psi over the entire bonding surfaces of the metals joined, insuring intimate contact and resulting in uniform, high-strength bonding. The prepared multimetal assembly is vacuum tested, then heated in an ordinary heat-treating furnace to sufficient temperatures to cause melting of thin layers of brazing alloy of suitable composition preplaced between the layers of higher-melting base metals. Since the vacuum is drawn only on the central area of the assembly where actual bonding is to take place, an expensive vacuum furnace is not required and the outside atmosphere is utilized to attain highest strength and uniformity of bond, by causing it to be exerted on the assembly or "pack" at elevated temperatures. Atmospheric pressure is aided by increased atomic mobility of the base metals at elevated temperatures to gain optimum bonding interface conformity. The resulting clad plate can be bonded effectively over areas of 1000 sq ft or more in one question, and meets ASTM-ASME specifications for clad plate for pressure-vessel use. It subsequently can be formed into shapes and welded by ordinary techniques for welding clad metals.

The initial noble-metal clad vessel produced for chemical service proved satisfactory and made the use of silver-clad steels practical and economical for the chemical industry. In effect, a new material had been provided to meet the requirements of advanced chemical-processing techniques. Since that first installation, 6 additional silver-clad vessels have been produced for the same service and are now in operation.

Petroleum and Petrochemical Industries

In the petroleum and petrochemical industries, new processes were developed to produce new chemicals from constituents in crude oils. Some of the catalysts used in these processes were highly corrosive. Many of the operations involved both high service temperatures and high pressures. Although the corrosion conditions have not been sufficiently severe to require noble metals, expensive proprietary nickel-molybdenum-iron alloys, were necessary for adequate corrosion protection. These particular alloys, owing to their elevated-temperature-strength properties, and in consideration of reduced corrosion resistance developed under certain heat treatments, had not yet been clad successfully by integral and complete bonding methods to carbon-steel backings. Until such a composite clad plate was made available, the operations of these advanced refining processes would be difficult and maintenance costs would be extremely high.

Vacuum bonding provided the answer to this problem. One pilot vessel of nickel-molybdenum-iron alloy vacuum-pressure clad to carbon steel has now been in service for over 9 months, exhibiting excellent corrosion resistance to a strong mineral acid at temperatures around 300° F. This pilot vessel is the forerunner of many more special alloy-clad vessels in the petroleum and petrochemical industries. It is interesting to note that as a result of this vacuum-metallurgical-cladding development, design engineers are now working on processes which will require clad metals of even more noble characteristics to allow reaction temperatures to be increased further.

Wood-Veneer Industry

In the wood-veneer industry, greater pressures and large press platens were required to produce higher quality veneer composites with greater area per piece. This increase in platen size made the regular method of drilling liquid flow channels through the thicknesses of solid metal plates (parallel to the plate surfaces) highly expensive and, in addition, increased drilling inaccuracies. Further, for more efficient heat exchange, contour channels were desired, but only straight channels, plugged at the ends, could be drilled.

This problem of providing liquid flow channels built into the thickness of steel plates was solved by machining the desired pattern of channels into one steel plate, then vacuum-brazing another flat steel plate over the grooves. The resulting composite clad heat-exchanger plate contained built-in liquid flow channels of desired shape with much improved accuracy of location with respect to the plate surfaces.

Alloy Casting Industry

In the alloy-casting and rolling industries, problems were encountered in removal of undesirable impurities from certain metals to improve corrosion resistance and physical properties. For example in the production of nickel-chromium-iron-molybdenum alloys for use in certain highly corrosive applications, it was necessary to limit the carbon content to less than 0.05%, preferably keeping it around 0.01 to

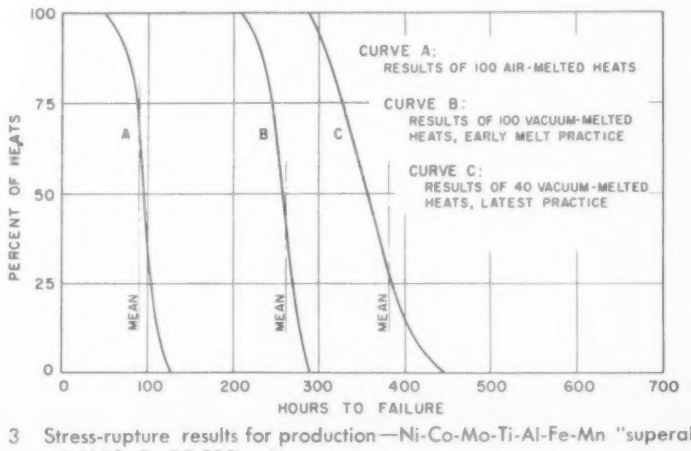

Fig. 3 Stress-rupture results for production—Ni-Co-Mo-Ti-Al-Fe-Mn "superalloy" heats at 1500° F, 32,500 psi

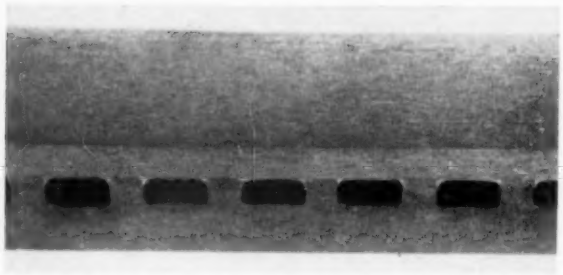

Fig. 4 Cross section of a vacuum-pressure-bonded hypersonic wind-tunnel cooling plate, Type 405 stainless integrally and continuously bonded to carbon steel

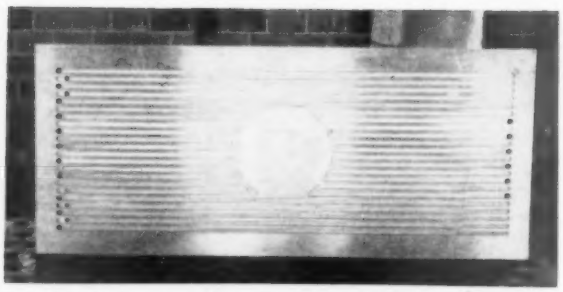

Fig. 5 Grooved carbon-steel base plate for hypersonic wind tunnel prior to assembly for vacuum brazing

0.03% to minimize the effects of carbide precipitation at welded joints. This problem was solved by vacuum-melting the alloy, by which sufficiently close control of contamination was attained. Corrosion tests on sensitized vacuum-melted alloys proved them highly satisfactory for the required service.

Another instance in which vacuum techniques were used to eliminate undesirable impurities from metals occurred in the titanium industry. Aircraft companies were encountering intermittent difficulties in forming titanium sheet. Analyses indicated that high hydrogen content in certain heats embrittled the titanium, resulting in forming failures during fabrication. Since that time, hydrogen has been eliminated from titanium through the use of the vacuum techniques as a standard procedure.

In addition to these specific instances of commercial vacuum-purifying of metals, it should be brought out that many of the more common metals, such as stainless steels, carbon steels, and nonferrous metals produced by ordinary methods have proved unreliable for newer process applications in which optimum properties with small allowance for safety factors are required. The metals, produced by ordinary production practices, normally contain resulting inherent defects such as segregations of nonmetallics, voids, entrapped hydrogen and other gases, and so on. When these defects and impurities have been removed by vacuum-melting and or heat treating, these common metals and alloys show remarkable increases in strength and other desirable properties (Fig. 3). Vacuum-melted common metals are now gaining in use, since, for an increase in cost of but a few cents per pound, metals of much greater homogeneity and much better properties can be obtained.

Aircraft and Missile Applications

One of the newest developments in aircraft and missile research is the hypersonic wind-tunnel now under construction on the West Coast. The problem of increased speeds of airflow necessitated the introduction of heated air into the tunnel, which, coupled with increased skin-friction effects, required intricate webs of liquid-flow channels to be built into the walls of the tunnel, $\frac{1}{4}$ in. from the inside tunnel surface. These channels were for the purpose of dissipating heat generated in the walls as rapidly and efficiently as possible to avoid distortion of airflow patterns through warpage in the tunnel structure. In order to satisfy these specifications, a new type of steel plate containing a network of small built-in liquid-flow channels had to be produced. From an investigation of all possible methods for producing these special plates, design engineers decided that the problem could best be solved by vacuum-joining techniques similar to those developed for liquid-cooled press platens. After a period of research and development involving design engineers and vacuum-metallurgical engineers, a channeled wind-tunnel plate was produced which successfully passed severe testing to destruction (Fig. 4).

Since that time, actual wind-tunnel plates have been built by vacuum-pressure brazing techniques. These plates are now in the process of fabrication into the hypersonic wind-tunnel unit. The channels in some of the plates are quite intricate (Fig. 5) and are of small cross section. Figures 6 and 7 illustrate some of the tests performed in the development of these plates.

Figure 6 shows that, upon severe bending, the channel supports fail at the base of the machined groove and not through the vacuum-brazed bond.

In Fig. 7 the ability of vacuum-brazing to accommodate itself to variations in gap between the brazed wind-tunnel plates is apparent. The bond zone to the left of center shows a typical vacuum bond in which pressure in addition to interface deoxidation is utilized. The bond zone to the right of center shows the ability of the process to adapt itself to filling a deliberately machined, 0.006-in. gap between the

Fig. 6 Bend test on channeled wind-tunnel plate section. Most failures in channel walls occur through the base steel at root of machined groove and not in vacuum-pressure braze

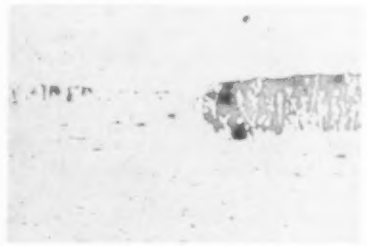

Fig. 7 Photomicrograph at X 100 of the filling of 0.006-in. intentionally machined gap in a vacuum-pressure bond interface. Reduced by $\frac{1}{3}$ upon reproduction

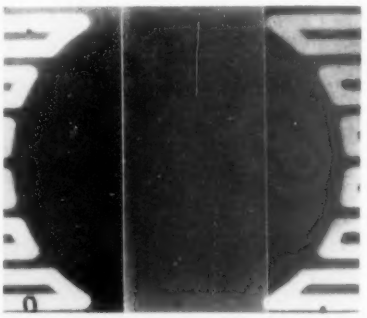

Fig. 8 X-ray photograph illustrating soundness and continuity of vacuum-pressure bond in channeled clad plate

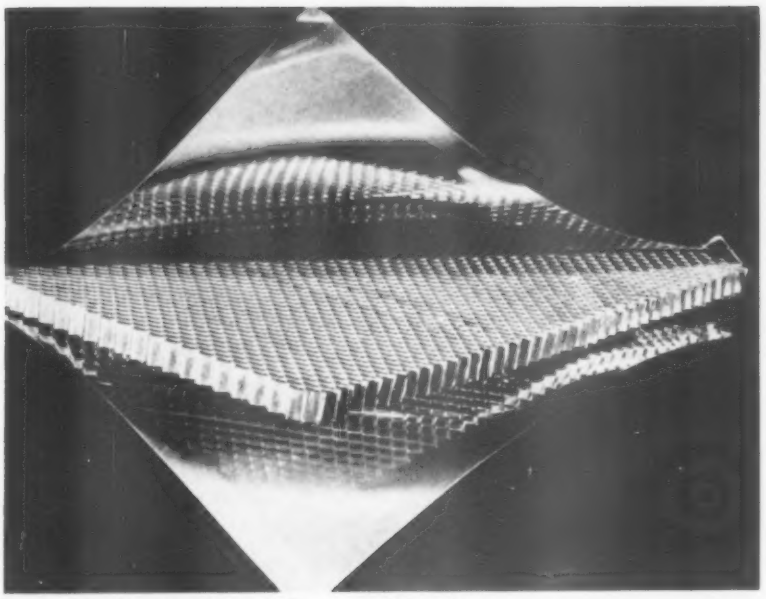

Fig. 9 Stainless-steel brazed "honeycomb" section

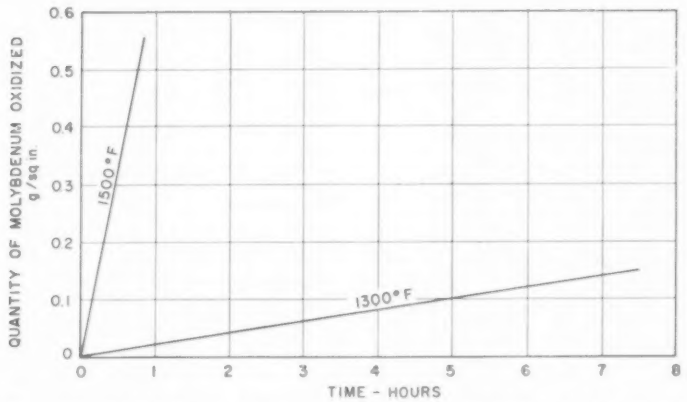

Fig. 10 Oxidation rates of unprotected molybdenum at 1300 and 1500° F

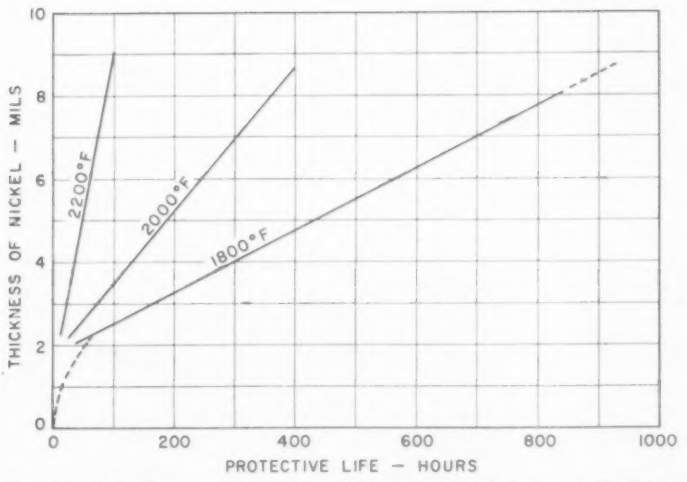

Fig. 11 Effectiveness of varying thicknesses of nickel over a 0.001-in. chromium layer in protecting molybdenum against oxidation

upper and lower plates. It will be noted that in the typical bond very little brazing alloy is used, and much of that is alloyed with the stainless upper plate and the carbon-steel base plate.

Figure 8 is a photograph of an X-ray negative which was used to examine the continuity of bond in the area where a viewing port will be installed. This photograph is evidence of the quality of high-strength vacuum-brazed bonds.

Another difficult design problem was evolved when higher-speed requirements for aircraft necessitated changeovers from aluminum to stainless steels in airframe and skin construction. These higher-density metals had to be designed to allow maximum structural strength with an absolute minimum of weight in order to achieve an acceptable wing-loading ratio. To solve this weight problem, aircraft engineers came up with the brazed, so-called "honeycomb" structural sections (Fig. 9), in which very thin stainless sheets are used to produce a lightweight section of great rigidity and strength. The brazing problems here are increased by the necessity for brazing intricate shapes made of very-thin sheets. This is a process which is as yet in the development stage; however, it is predicted that vacuum-brazing techniques will play an important part in solving the problems of transition into commercial production. The ability consistently to produce strong, uniformly brazed "honeycomb" sections of various designs on a production basis will mark an important milestone in aircraft-engineering progress.

High-Temperature Applications

As mentioned previously, the aircraft industry is faced with the problem of using metals in service ranges of 2000 to 3000° F in propulsion units and missiles. It is quite possible that vacuum-melting techniques will allow the development of a new high-temperature alloy which will exhibit satisfactory strength at these temperatures and have satisfactory oxidation resistance in atmospheric gases. In the meantime, however, another channel of research is being followed in an attempt to use present high-temperature metals to greatest advantage. This phase involves the development of oxidation-resistant claddings for metals such as molybdenum, tungsten, tantalum, columbium and others, in order that they may have protection in high-temperature service while their exceptional high-strength properties are utilized (Figs. 10 and 11).

Vacuum-cladding appears to present the greatest potential for solution of this problem and accelerated research on it is now in progress at certain high-temperature metallurgical research cen-

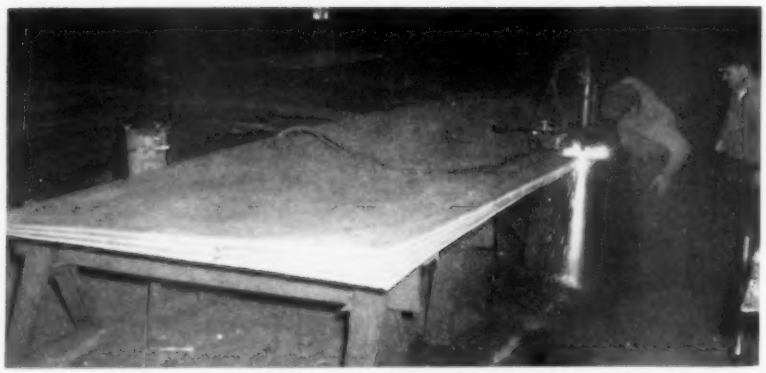

Fig. 12 Opening a vacuum-pressure clad assembly wherein six carbon-steel plates were clad simultaneously with stainless steel

ters throughout the country. This is a phase of high-temperature research which could yield more rapid results than is probable in the development of a single high-temperature alloy which must have both high - temperature strength and oxidation resistance, since each component of the clad materials is required to exhibit only one major high-temperature characteristic. Present research on high-temperature cladding appears promising; however, much is yet to be done in the development of suitable high-temperature brazing alloys, suitable oxidation-resistant cladding alloys, and satisfactory techniques of integrally bonding the cladding alloys to metals with high-temperature strength.

Atomic-Energy Applications

As a final example of problems of metallurgical research faced by industry as a result of advanced development in the process and equipment fields, the effects of radiation on metals should be mentioned. Problems have arisen as a result of substantial changes in characteristics of certain metals as a result of their exposure to atome radiation. One of these changes involves corrosion characteristics. In designing containment vessels and equipment for atomic-energy processes, engineers cannot use established corrosion data, since radiation drastically changes the corrosion properties of many metals and alloys. As a result, new metals and alloys must be found which will resist corrosion in various media under conditions of radiation. This again involves melting, heat treating, and joining of many of the more unusual metals, some of which are sensitive to atmospheres at elevated temperatures. The problems involved in this field are now under consideration; and, although much of the work on this phase of metal application is classified, alloy development, cladding, and heat-treatment research is in progress and there is no doubt that vacuum-metallurgical techniques will play an important part in it.

Industrial Applications of Vacuum-Brazing of Other Common Metals and Alloys

From the specific examples of engineering and construction problems solved by vacuum-metallurgical techniques, or from those yet under research and development, it is obvious that this versatile tool must have many other applications which have not yet been considered. Lest the impression be created that these techniques are only applicable to and commercially feasible with unusual metals and engineering designs which can be produced in no other manner, attention is called to economical commercial operations for large-scale production of ordinary clad steels.

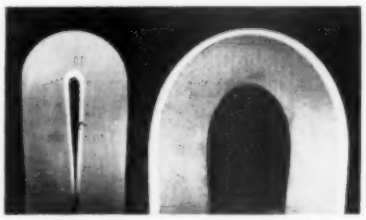

Fig. 13 Cross-section view of 180 deg bend tests on vacuum-pressure-clad steels

Figure 12 illustrates the manner in which six or more 8 x 25-ft stainless-clad plates can be made in one heat. The single unit shown during the process of opening the "pack" involves 1200 sq ft of finished, integrally and continuously bonded vacuum-pressure clad plate. Figure 13 illustrates the continuity and strength of the vacuum bonds obtained as revealed by polished and etched cross sections of test bends made on ordinary vacuum clad-plate.

Figures 14 through 16 show some of the large vessels now in chemical, petroleum, and paper-pulping service, fabricated from vacuum-clad stainless steel, Monel, nickel and Inconel. All of these materials are applied on inexpensive, low and medium-carbon-steel backings.

Additional metals which have been clad to steels successfully by vacuum-pressure techniques are titanium, zirconium, tantalum, molybdenum, silver, gold, platinum, aluminum-bronze, copper, lead and beryllium-copper. Some of these metals and alloys in the clad form are still awaiting industrial applications, which, no doubt, will develop in the near future.

Summary

Vacuum metallurgy is rapidly assuming a vital role in making possible advanced industrial development of this period. It has succeeded in transforming the "age-old art of brazing" into a new and promising modern industrial tool, and has proved to be the solution for many difficult industrial problems which could be solved by no other means at our present stage of metallurgical knowledge.

The same can be said for vacuum-casting techniques, vacuum-purification and degassing techniques, and vacuum heat-treating techniques. All of these have enabled metallurgists to supply industry with ductile metals heretofore not commercially available and to improve greatly the properties of available metals.

The purpose of this paper has been

Fig. 14 Ninety-one-ft combination tower of vacuum-pressure-clad Monel and stainless steel on carbon steel for petroleum industry

Fig. 15 Paper pulp digesters of Type 316-L stainless-steel vacuum-pressure-clad to carbon steel

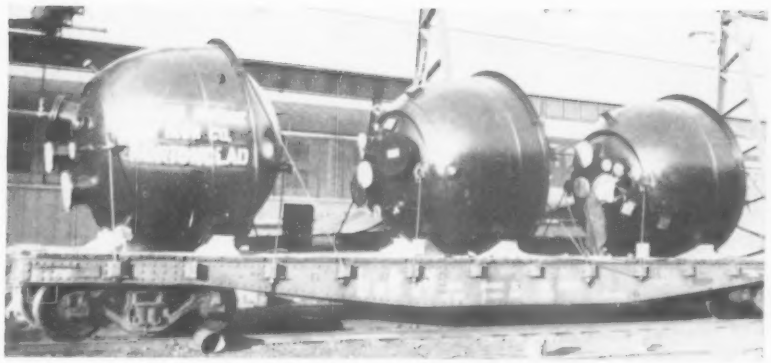

Fig. 16 Nickel-clad spheres for chemical service produced by vacuum-pressure brazing

to present some of the problems which have been solved by vacuum-metallurgical methods, and to discuss several problems which have not yet reached the stage of solution but for which vacuum techniques appear to have particular potential. This discussion may stimulate thoughts and ideas which could be translated into new and important industrial applications for this most versatile tool, leading to solutions of other heretofore unsolvable industrial problems.

The field of vacuum melting, joining, and heat treating is one in which great areas for additional productive research exists, and in which research investments can be expected to reap rich rewards in industrial and process development in the future.

Acknowledgments

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Office of Naval Research, Navy Department, Washington, D. C.

Standard Oil Company of California, San Francisco, Calif.

Haynes Stellite Co., Kokomo, Ind.

Fansteel Metallurgical Corp., North Chicago, Ill.

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EFFECT OF TIME AFTER DEPOSITION ON HYDROGEN CONTENT AND MECHANICAL PROPERTIES OF COVERED-ELECTRODE WELD METAL

BY J. COLBUS

Abstract by **Gerard E. Claussen** of "L'Influence du Temps de Sejour a Temperature Ambiante et du Recuit Sur la Teneur d'Hydrogene et Sur les Caracteristiques Mecaniques. Notamment Sur L'Allongement et la Striction du Metal Depose Par Fusion D'Electrodes," published in *Inf. Soudure*, **46**, 277–283 (1956); **47**, 14–18 (1957). The author is associated with the Federal Welding Institute and Materials Testing Laboratory in Saarbrucken.

Dr. Claussen is associated with the Development Laboratory, Linde Co., Newark, N. J.

Weld metal deposited in accordance with French Standard A-81-302 was analyzed for hydrogen and was tested for mechanical properties one day and six weeks after deposition. Time at room temperature lowered the hydrogen content and raised the elongation and reduction of area as shown in Table 1. These changes seemed to conform with current ideas on the effect of high pressures of hydrogen in predisposing steel to brittle failure by triaxial tensile stress. The experiments also confirmed work by Roux (*Soud. Tech. Connexes*, **8**, 160–169 (1954)) which showed that the hydrogen content depends on the speed of welding.

Table 1—Hydrogen in All-Weld Metal

Type of electrode	*Yield strength, psi*	*Tensile strength, psi*	*Elongation, %*		*Reduction area, %*		*Notch-impact value, mkg/cm²*		*Hydrogen content, cm³/100 g*	
			After 1 day	*After 6 wk*	*After 1 day*	*After 6 wk*	*After 1 day*	*After 6 wk*	*After 1 day*	*After 6 wk*
Heavy rutile cellulose covering	64,000	74,000	20	25	..	..	..	..	7.3	2.5
Thin cellulose covering	50,000	64,000	22.3	27	..	..	..	..	10	6
Medium heavy rutile-cellulose covering	49,000	63,000	26.5	30	46	64	10.4	9.7	7.2	4.4
E6020 type	50,000	66,000	27.4	30	48	63	9.3	9.6	6	2.2

BASIC CHARACTERISTICS OF SOME HEAT-RESISTING BRAZING FILLER MATERIALS

Paper by W. H. Chang was published in September 1956 issue of The Welding Journal, 35, Research Suppl., pp. 431-s to 443-s

DISCUSSION BY FORBES M. MILLER and ROBERT L. PEASLEE

In reference to the article by Dr. W. H. Chang titled "Basic Characteristics of Some Heat-Resisting Brazing Filler Materials" that appeared in the September 1956, WELDING JOURNAL, the author should be commended on an extremely comprehensive evaluation of the strength properties of these materials. The careful way in which the tests were devised and conducted and the extensive theoretical discussions should make this work of considerable value.

It is well known that there is a rapidly increasing use of the common heat-resisting materials and a large number of new alloys are constantly being developed. This creates a need and a desire for fabricators and designers to use more brazed assemblies. This, in turn, necessitates the need for more information about brazing filler materials and brazing procedures for these heat- and corrosion-resistant alloys.

However, as in any scientific endeavor, the value of this work lies in how well the users of the data understand and interpret it. As manufacturers and large users of high-temperature brazing alloys, we are constantly testing and seeking ways to obtain data that will be of practical use to designers of brazed components for high-temperature use.

In studying this report we can first refer to Tables 5, 6 and 7. These tables show that as the joint clearance increases on butt-brazed tensile-test bars brazed with the nickel-chromium-boron and nickel-chromium-silicon filler materials, the room-temperature ultimate tensile strength and the percent of elongation drops. However, test bars brazed with the gold-nickel alloy appear not so sensitive to joint clearance. The photomicrographs of the nickel-chromium filler materials reveal less diffusion into the base metal on joints of the greater clearance. When the clearance approaches six-thousandths of an inch, there appears to be a cast or dendritic structure. This low elongation or so-called brittleness in the joint is held responsible for the lower ultimate tensile-strength figures. On the other hand the gold-nickel joints did not show this drop in elongation as the clearance increased. This, of course, is because the gold-nickel alloy is, in itself, very ductile. We believe these tests show a true picture; however, we do not believe that the so-called brittle condition is indicative of an inferior joint. Here is where interpretation of data comes in.

First of all, to test the actual bond strength of an extremely ductile alloy brazed with a less-ductile filler material is virtually impossible using standard techniques. Consider what happens when a butt-brazed tensile bar is stressed in a tensile machine. The ductile base metal will elongate considerably after the yield point is passed while the joint area will remain rigid. This throws high stress concentrations at the edges of the joint which will cause a joint failure somewhere between the yield point and the breaking point of the base metal. The reported ultimate strength, then, is actually not the bond strength of the joint but an average stress across the joint cross section. If it could be determined by some simple and accurate means, no doubt it would be found that the joint stress was much higher than the base-metal ultimate strength. If we study Tables 5, 6 and 7 again we will see that in most cases the nickel-chromium alloys had a yield point equal to the yield point of the base metal. No stress concentrations occurred below the yield point because both the base metal and the joint were stretching uniformly (elastically). In other words, the reason the joints with the closer clearance exhibited higher breaking strengths is because the greater diffusion caused more elongation of the joint. This resulted in less stress concentrations.

Some of the joints did, however, break in machining and some broke below the base-metal yield point. This definitely is due to an abnormally low bond strength. This weak bond should not be considered as an abnormality in the brazing *alloy*. Nor should it be considered due to brittleness. It is possible to have a brittle material with very high bond strength. This weak bond should be considered as an abnormality in the brazing *cycle*. There are many factors in the brazing cycle that could cause this as will be mentioned later; however, one thing could be mentioned here. We have found that weak bonds in joints of wide clearances are sometimes caused by insufficient alloy applied or insufficient flow to completely fill the joint without shrinkage.

The next topic of discussion should pertain to the property of ductility in joints brazed with the nickel-chromium alloys. There are very few commercial brazing operations where the time, temperature, clearance and other factors of the brazing cycle can be specified and controlled to the extent that a joint of 20 to 40% elongation will be provided as reported on some of the test bars in this report. However, there are hundreds of components successfully operating today in aircraft and nuclear reactors under high temperatures and high stresses, that have been brazed with these alloys. The reason for this success is because these high percentages of elongat on are not actually needed in service. The maximum strength properties that can be used in any brazed joint in service are bond strengths equal to or slightly greater than the yield point of the base metal, and sufficient ductility to relieve stress concentrations occurring in service. According to Bock,[1] in his article on "Why Specify Ductility," the percent of elongation of one to two percent is sufficient for almost any highly stressed component if it is properly designed.

Bock also stated that there are good reasons for specifying ductility in base metals. These reasons, however, are related to controlling the quality of a material, primarily, and should not

Forbes M. Miller is Research Metallurgist and **R. L. Peaslee** is Vice-President, Wall Colmonoy Corp., Detroit, Mich.

be considered as a quantitative property that will be used in service.

It is important then for designers and fabricators of high-temperature components to realize that in a brazed joint it is not necessary to have ductility equivalent to the base metal. The most strength that is possible to use in service is a bond strength slightly higher than the yield strength of the base metal and, as mentioned above, sufficient ductility to resist stress concentrations.

Now to get back to the basic idea of this paper which pertains to the effect of clearance on a butt-brazed joint. I do not wish to convey the idea that joints with wide clearances are always as strong as joints with narrow clearances.

On wide joints there may be another factor besides the one of insufficient alloy previously mentioned. It may be that the brazing alloy sometimes freezes to form a coarse dendritic or columnar structure that, relatively speaking, has a lower cohesive strength than a joint which has considerable diffusion. The significance of these points, then, is strictly a matter of engineering. In other words on joints of high stress, such as turbine blades or turbine shafts, the clearances and fits should be held close and all the other variables of the brazing cycle should be controlled so that the strongest possible bond is obtained. On the other hand on a large sheet-metal structure where a joint is located in areas of low stress there should be no worry if clearances vary from say, zero to 0.006 in.

The author refers to lack of information about application of these alloys. We quote: "It is disturbing to note that in spite of growing popularity of these new brazing alloys basic information defining the condition under which these alloys should be applied is still lacking." We assume the author is referring to conditions of service here. The good elevated-temperature strength properties and oxidation-resistant properties previously mentioned by the author, their good resistance to corrosion in fused metals and salts up to 1500° F, their excellent flow and bond characteristics make these alloys usable in almost any kind of elevated-temperature application. There are limiting factors, however, but these factors pertain to the brazing procedure more than to the brazing alloy. In other words, in order to braze certain aluminum- and titanium-bearing base metals, extremely thin materials (such as two-thousandths inch thick honeycomb materials), clad material (such as stainless-steel clad copper) or components of extremely complex design, the success lies in how the parts are to be brazed so that the joints will be satisfactorily bonded. We agree that the amount written about these alloys is by no means complete but there is considerable information available. For example, the articles by Peaslee and Boam in the *Iron Age*[2] and THE WELDING JOURNAL,[3] and the article by Rose and Lewis in THE WELDING JOURNAL[4] do provide much test data and information about brazing procedures. It is not hard to realize why this information is not complete if we realize that in this very new field practically every brazed assembly for aircraft and nuclear-power application is an engineering project in itself. Listed below are some of the major factors that must be considered in working out such a brazing procedure:

1. Over-all design and shape of assembly.
2. Design of brazed joint.
3. Base metal.
   - (*a*) Composition and treatment, consisting of such factors as heat treatment, cold working, plating, oxidation, etc.
   - (*b*) Condition and finish, consisting of such factors as pickling, blasting, surface roughness, etc.
4. Brazing alloy (in as-received condition).
   - (*a*) Composition.
   - (*b*) Cleanliness and homogeneity (before brazing).
5. Surface preparation of joint, consisting of such factors as blasting, pickling, machining, grinding and others.
6. Joint clearance.
   - (*a*) Zero clearance.
   - (*b*) Press fit.
   - (*c*) Clearance controlled to close tolerances.
   - (*d*) Clearance with wide tolerances.
7. Application of brazing alloy.
   - (*a*) Amount of alloy.
     1. Quantity per unit length.
     2. Total quantity for joint.
   - (*b*) Placement of alloy.
     1. Inside or outside of joint.
     2. Heavy mass next to light mass.
     3. Form of alloy such as powder, wire, rings, etc.
8. Method of heating such as gas or electric fired furnaces, induction, torch, arc, etc.
9. Fixturing, involving such factors as mass of fixture, radiation shielding of, etc.
10. Atmosphere and fluxes, involving such things as chemistry of atmosphere, dew point, purity, etc. Residue from fluxes, removal and corrosion problems.
11. Heating cycle.
    - (*a*) Rate of heating.
    - (*b*) Time above solidus.
    - (*c*) Maximum temperature.
    - (*d*) Rate of cooling.

Even though the brazing alloy is an important factor, the above information shows that it is not the only factor. There are a few factors in the brazing cycle, however, that are a function of the brazing alloy. For example, of the three nickel-chromium alloys studied in this project the nickel-chromium-boron alloy No. 1 and the nickel-chromium-silicon alloy should be used where maximum strength and oxidation resistance is desired and where a brazing temperature of 2150° F or higher can be tolerated. The nickel-chromium-boron alloy No. 2 is best used on extremely thin base metals, clad metals or on base metals where the brazing temperature cannot be in excess of 1900 to 2000° F.

The author mentions that the time at temperature and surface preparation showed no noticeable difference in the test results. This may have been because the ultimate properties were reached on his test bar in all cases because the other brazing variables were so carefully controlled. However, in production brazing our experience has shown that a properly gritblasted surface is best for producing consistently good results.[2,3] Time at temperature is also an important factor in commercial brazing. But here the heating rate should also be considered, especially when brazing temperature is high. For example, if it took 2 hr to heat an assembly from the brazing-alloy liquidus to the brazing temperature, a holding time of 5 or 30 min would probably not show much difference.

We certainly do not feel that the ultimate has been reached as far as brazing alloys for high-temperature applications are concerned. Our research staff is constantly pointing toward new developments in this direction. However, we do feel that before the existing alloys can be used to their ultimate, or before better ones can be developed, it will become necessary for researchers to realize that the old brazing concepts pertaining to mild steel, exothermic atmospheres, copper and silver filler materials are no longer applicable to these new developments. Also, it will become necessary for researchers to discard other concepts such as: the brazing alloy must be ductile; the brazing alloy must not contain metallic-compound formers such as phosphorus, boron and silicon; the reluctance to consider the development and use of new nonharmful fluxes where necessary in order to get proper wetting.

In order to improve components for elevated-temperature service in aircraft and nuclear-reactor applications it is of course necessary to design with the latest and best high-strength alloys. To reach the ultimate performance at the most economical figure, designing for brazed joints is also necessary. The following recommendations are made for future research on brazing.

1. Develop brazing alloys with even better cleanliness and flow properties that have equal or better oxidation and corrosion resistance.

2. Develop alloys with shorter melting ranges and proper melting temperatures for the specific base metals used.

3. Develop less complicated and more reliable brazing techniques that will insure a good bond for any type of base metal under production conditions. Such things as purer atmospheres, high vacuum techniques and fluxes, such as volatilizing or disappearing fluxes, perhaps are a few of the things that should be investigated most extensively.

4. Conduct tensile-shear tests and butt-tensile tests to a specified elongation (such as 2 to 5%) rather than to failure. This should be sufficient in most cases to determine if the brazed joint has satisfactory strength for service. These should be conducted at elevated temperatures as well as at room temperature.

5. Stress-rupture tests should also be conducted on brazed specimens to determine if their properties change adversely with respect to time at elevated temperature, particularly in shear[2,3] It may be possible that in stress-rupture tests the joint is not subjected to stress concentration as severely as in standard butt, tensile and shear tests. If this should be true then the test would be a more accurate evaluation of the true joint strength.

6. Elevated temperature tests should be conducted on the gold-nickel alloy to determine if its properties are still relatively good.

In conclusion then, we believe that future research should be conducted wherever possible and by whomever possible in which new, unbiased concepts be used to engineer joint designs, brazing procedures, physical and chemical property requirements, brazing-alloy development, brazing-alloy selection and brazed-joint testing. If such research is conducted on the same high plane as this piece of work, then progress will be rapid in this young and extremely important field.

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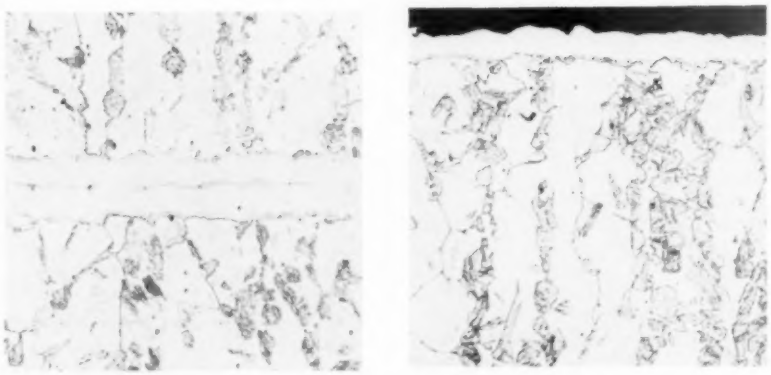
AUTHOR'S CLOSURE

The author wishes to thank Messrs. Miller and Peaslee for their extensive discussion of the paper. There is little to comment on the latter part of the discussion, in which they admirably enumerated the factors to be considered in establishing a proper brazing procedure, and suggested avenues of future research. The author, however, finds it difficult to concur with the idea that there is really basic conflict between the "old" brazing concepts and the concepts for applying new brazing alloys. In brazing, as in any other branch of technology, the foremost guiding principle has been and will continue to be the use of materials and processes which accomplish the purpose most economically with the least complications. To this end, the "old" brazing concepts remain as valid for the new brazing alloys and associated brazing procedure as for "mild steel, exothermic atmospheres, copper and silver filler materials." Although the author is a newcomer to the brazing field, he knows of no "old-timers" who fail to recognize the above principle and who insist that the brazing alloy must be ductile and must contain no metallic-compound formers.

The important point which the author would like to have cleared up pertains to the effect of joint clearance on joint strength. It is commonly recognized that the state of stress across a brazed joint during tensile testing is a complex situation. The author, in general, agrees with Messrs. Miller and Peaslee on their stipulation on the possibility of stress concentration across a joint consisting of a ductile base material brazed with a less ductile filler material. However, this stipulation assumes a homogeneous joint structure and thus fails to recognize the effect of compound phases, which prevails in the thick (large clearance) joints brazed with the Ni-Cr-base alloys under discussion. In this case, the stress concentration will be more effective around the compound phases, rather than at the base material adjacent to the joint interface, as stipulated in the discussion. In Fig. C-1 are two photomicrographs of AISI 405 butt-brazed with the Ni-Cr-Si-alloy at a clearance of 0.002 in., before and after tensile testing. It is clearly indicated that the fracture occurred not at the joint-base metal interface, but along the plane where the brittle phases were segregated prior to test. It has been found that the embrittling effect of these phases is even better demonstrated in an impact test. The failure of some brazed specimens (with large clearances) during machining was due primarily to the impact received during machining, rather than to the lack of brazing alloy in the joint. Whereas a coarse dentritic or columnar structure is generally weak as the discussers pointed out, such a structure did not exist in the joints under discussion except with respect to the formation of a continuous layer of the brittle phases at large clearances. As explained in the paper, these layers



(A)—Before tensile test (B)—After tensile test

Fig. C-1 AISI 405 butt-brazed with Ni-Cr-Si alloy at a clearance of 0.002 in. X 100

are conducive to premature failure of the joint.

From the foregoing comments, it must be concluded that the higher breaking strength exhibited by joints with "zero" clearance originates from the absence of the brittle phases. Without these phases, the joint itself neither suffers stress concentration nor yields plastically until the ultimate strength of the base material is approached. That this is so follows from a consideration of the radial stress exerted on the joint by the surrounding base material, which restricts the longitudinal extension of the joint. As a result, the effective yield strength of the brazing alloy in the joint is raised to a value considerably above the yield strength of the bulk brazing alloy. In Tables 5, 6 and 7 the yield-strength values pertain to those of the brazed specimens (or base materials) and not to the brazing alloys, as interpreted by the discussers.

The question, raised in the discussion, whether a joint brazed with the Ni-Cr-base alloys at a larger clearance is inferior to one brazed at a smaller clearance depends on the definition of inferiority. Based on the metallurgical bonding at the joint-base metal interface, a thick joint should be just as sound as a thin one. However, from the viewpoint of load-carrying capacity, a thin joint without the brittle phases is definitely superior.

In conclusion, the author would like to recapitulate the purpose for which the paper under discussion was written. This paper was meant to show some basic characteristics of brazing alloys, which demand consideration when choosing a certain brazing alloy for a particular application. The paper emphasized the advantages of having a solid-solution type brazed joint over a joint with a multiphase microstructure. It was never intended to imply that the gold-18 nickel alloy, as such, was better than any of the Ni-Cr-base brazing alloys. If such an impression was created in the paper, the author hopes that it will be cleared by the helpful discussion given by Messrs. Miller and Peaslee.

RESEARCH NEWS

A Handbook on the Properties of Cold Worked Steels. L. J. Ebert, Case Institute of Technology for Watertown Arsenal Laboratory, U. S. Army. June 1955. 113 pages. (Order PB 121662 from OTS, U. S. Department of Commerce, Washington 25, D. C., $3.) Data gained from five years of research into the extent to which cold worked steels might replace the more strategic heat treated alloy steels are contained in this volume. The engineering information is presented in basic handbook format for the use of design and ordnance engineers. The data, its analysis and conclusions resulted from many thousands of tests of the engineering applicability of cold worked steels. The data are typical of steels which could be supplied by industry. The first section of the handbook, useful particularly to new users of cold worked steel, contains a tabular presentation of the important engineering properties of the material and factors to be considered in design selection. Chapters deal with mechanism of cold working, composition effects, residual stresses, directionality, benefits and limitations, and guidelines to selection and cost of the cold worked product. A final section reviews successful applications of the material.

Interrelation of Fatigue Cracking Damping and Notch Sensitivity. L. J. Demar, University of Minnesota for Wright Air Development Center, U. S. Air Force. March 1957. 164 pages. (Order PB 131025 from OTS, U. S. Department of Commerce, Washington 25, D. C., $4.25.) This volume is the fourth in a series dealing with the general subject of fatigue cracking. Results of previous studies are summarized, including observations on the changes in damping as a function of frequency, stress level, and stress history at a given stress level. Relations among damping elasticity, fatigue, and notch sensitivity of metallic materials are discussed. The body of the report contains results of numerous fatigue tests performed on a variety of metallic materials in which observations were made of the changes in damping and stiffness properties of the specimens and of the development of fatigue macrocracks. These test results are discussed in relation to previous investigations, and new relations between dynamic properties of materials are evolved. Used for the investigations were alloy N-155, a high-carbon steel in two conditions of heat treatment, gray iron, aluminum alloy, J-1 magnesium alloy, and SAE 1020 steel.

An Investigation of Intergranular Oxidation in Stainless Steels and High-Nickel Alloys. C. A. Siebert and others, University of Michigan, for Wright Air Development Center, U. S. Air Force. Oct. 1956. 53 pages. (Order PB 121795 from OTS, U. S. Department of Commerce, Washington 25, D. C., $1.50.) When a metal is subject to an oxidizing medium, a continuous oxide layer is usually formed on the exposed surface. This oxide layer generally increases in thickness with increasing time and/or temperature change. With some alloys, however, oxidation also occurs in the grain boundaries ahead of the metal-oxide interface. This phenomenon is examined in this report. Intergranular oxidation measurements were made on oxidized Chromel ASM, Hastelloy B, and commercial and vacuum-melted type 310 stainless steel alloys. In general, intergranular penetrations increased rapidly with stress after a certain minimum value was reached. This minimum value, or threshold stress, was determined for each alloy at various temperatures, along with the weight gained during oxidation. Among the results, it was found that most of the alloys followed the parabolic oxidation law.

Investigation of the Creep-Rupture Properties of Mo-V Low-Alloy Steels. P. Shahinian and J. R. Lane, Naval Research Laboratory. May 1957. 23 pages. (Order PB 121953 from OTS, U. S. Department of Commerce, Washington 25, D. C., 75 cents.) It appeared from this research that the content of molybdenum, a strategically-scarce material, can be reduced in low-alloy steels and replaced by vanadium, which is in greater supply, without affecting the high-temperature properties of the alloys in standard use. Creep-rupture properties were determined for low-alloy steels containing more vanadium and less molybdenum than the usual compositions. The high-vanadium steels (0.5 to 0.7 percent) were superior to the low vanadium type at 1100° F in both strength and ductility. A reduction in molybdenum content was affected without lowering strength at 1100° F.

CRACK INITIATION AND PROPAGATION IN THE V-NOTCH CHARPY IMPACT SPECIMEN

Simple variation in the Naval Research Laboratory low-blow technique permit differentiation between the crack-initiation and crack-propagation stages of fracture in V-notch Charpy impact testing

BY CARL E. HARTBOWER

ABSTRACT. It has been suggested that brittle fracture may be distinguished from ductile fracture by the manner in which the initiating crack is propagated; a brittle-fracture crack is propagated by continuous release of the elastic-stress field surrounding the crack, whereas a ductile-fracture crack requires plastic deformation work to extend the crack. Because the energy value obtained from conventional V-notch Charpy impact tests integrates the crack-initiation and crack-propagation stages of the fracture process, it was deemed necessary to investigate a modification of the conventional impact testing technique to permit differentiation between the crack initiation and propagation stages.

Two approaches were investigated. Both involved the initiation of a crack by means of an initial low-energy blow of the impact-machine pendulum. The first method determined the highest temperature at which the initial low blow caused complete fracture of the test specimen, i.e., the temperature at which the low-blow-initiated crack propagated by continuous release of the elastic-stress field developed by the initial blow. The second method required the measurement of lateral expansion after the crack-initiating low blow and again after a second, fracturing blow. The use of lateral expansion as a measure of the plastic-deformation work was based on the previously established proportionality between lateral expansion and energy absorbed (work done) in fracturing the test bar. When the fracturing blow did not produce a significant increase in lateral expansion, the plastic-deformation work done in extending the initiating crack was essentially zero and the fracture was considered to be brittle. The highest temperature permitting crack propagation without plastic-deformation work to extend the crack was taken to be the brittle-fracture transition temperature.

Multiple low blows delivered at or below the brittle-fracture transition temperature provided a possible explanation for brittle fractures in service which have occurred under conditions of static load and/or low nominal stress. For example, specimens from highly notch-tough material, subjected to an initial low blow of 20 ft-lb, fractured under a single additional 10 ft-lb capacity low blow with no measurable plastic deformation attending the second (crack-propagating) blow when tested below the transition temperature. Thus, an analogy is suggested between performance as observed in the laboratory test specimen and the case of a bridge, ship, or storage tank which is subjected to local plastic yielding (and possibly crack initiation) at points of stress concentration in one load cycle, and then fractures in a brittle fashion in a subsequent load cycle involving low nominal stress.

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The opinions or assertions contained herein are the private ones of the author and are not to be construed as official or reflecting the views of the Department of the Army.

Introduction

Background

The following report is the third of a series with the over-all objective of evaluation and improvement of the Charpy impact test. The first paper discussed the Poisson effect as it occurs in Charpy impact specimens.[1] It demonstrated that the deformation attending the fracture of a Charpy bar can be measured as either lateral contraction occurring under the notch or lateral expansion at the compression surface of the test bar. In pearlitic steel, a linear relationship was shown to exist over an appreciable range of energy absorption between lateral contraction, lateral expansion and energy to fracture.

The objective of the second paper was to evaluate certain performance criteria and a particular definition of transition temperature for use in V-notch Charpy slow bend tests.[2] Transition temperature was defined as the highest temperature at which sudden and complete fracture occurred at maximum load, i.e., zero energy after maximum load (Fig. 1). The definition was based on (1) an experimental observation by Raring that the start of crack propagation in the thickness direction of V-notch Charpy slow-bend bars coincides with the maximum in load as determined from the load-deflection diagram,[3] and (2) a suggestion by Orowan that one may differentiate between ductile and brittle fracture by noting the manner in which the initiating crack is propagated;[4] a brittle-fracture crack is propagated by continuous release of the elastic-stress field surrounding the crack, whereas a ductile-fracture crack requires plastic-deformation work to extend the crack. Thus, with zero energy (work) after maximum load, fracture was considered to be brittle. The deformation (lateral expansion) measured in the specimens which suddenly and completely fractured at maximum load was assumed to have occurred prior to crack propagation. An appreciable amount of deformation was found to occur in V-notch Charpy slow-bend specimens at the transition temperature; it was concluded that the amount of deformation attending brittle fracture provided a measure of the relative embrittlement of a series of steels or a given steel under various metallurgical conditions. Based on the assumption that the deformation measured in the fractured test specimen preceded brittle-crack propagation, it was concluded that the deformation measured in specimens developing brittle fracture reflected only the crack-initiation stage of fracture, i.e., the resistance of the material to bending and formation of the initiating crack.

In V-notch Charpy impact testing, the energy value read from the calibrated machine pendulum constitutes an integration of the various stages of the fracture process, i.e., a summation of the energies required for bending, crack initiation, and crack propagation. A technique used at the Naval Research Laboratory[5] provides a method for separating the crack-initiation and crack-propagation stages. In the work conducted at NRL, specimens were tested

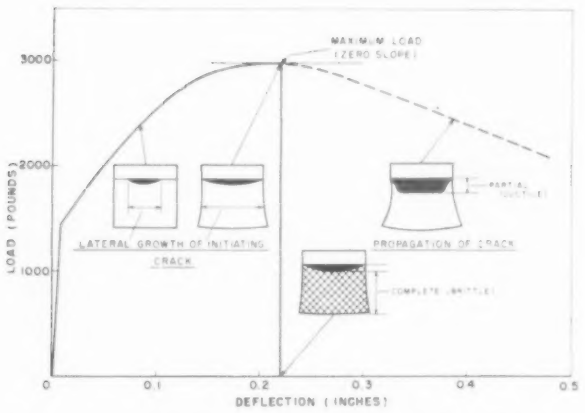


Fig. 1 Crack initiation and propagation in V-notch Charpy slow-bend testing

The depth of the initiating crack is essentially constant up to maximum load; whereas, the width of crack increases laterally until at maximum load the crack extends to the sides of the test specimen. Beyond maximum load, the crack propagates in the thickness direction with an attendant loss of load-carrying capacity. When the initiating crack propagates by continuous release of the elastic-stress field surrounding the crack (zero energy after maximum load), the fracture is considered to be brittle

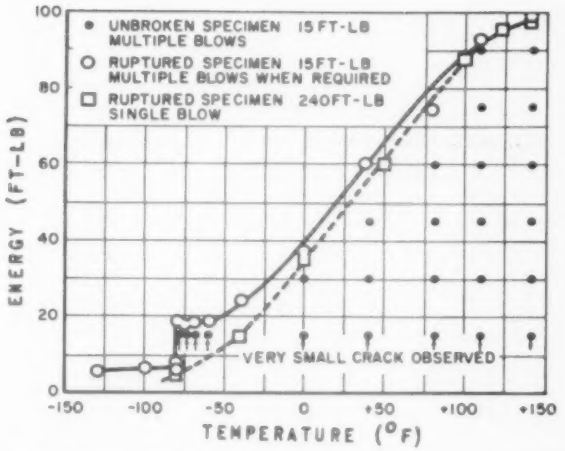


Fig. 2 Transition behavior obtained from low-energy blows

in an impact machine in the conventional manner except that the kinetic energy of the hammer was varied by changing the mass and/or velocity of the hammer. Using multiple low-energy impact blows on medium-carbon steels, the investigators reported that the energy required to initiate a crack is constant over a wide range of temperature, whereas the energy absorbed in extending a crack varies with temperature (Fig. 2).

Objective

It is the objective of this investigation to introduce a simple variation in the NRL low-blow technique which will permit differentiation between the crack-initiation and crack-propagation stages of fracture in V-notch Charpy impact testing.

Materials

The material used in this investigation was a single heat of steel purchased in the form of $^9/_{16}$-in. square, annealed, machine-straightened, aircraft-quality, electric-furnace AISI-4340 hot-rolled steel rods.

The chemical analysis obtained from 20 samples picked at random from the rods was as follows:

Chemical Analysis, %	
C	*Mn*
0.37–0.38	0.75–0.77
Si	*S*
0.27–0.28	0.013–0.015
P	*Ni*
0.013–0.016	1.73–1.77
Cr	*Mo*
0.83–0.86	0.25–0.27

Three heat treatments were used to develop a variation in hardness (strength) in the AISI-4340 steel:

Condition A (Hardness R_C 27)

a. Heated to 1600° F, held 1 hr, oil quenched
b. Heated to 1200° F, held 1½ hr, oil quenched
c. Heated to 570° F, held 3 hr, air cooled

Condition B (Hardness R_C 34)

a. Heated to 1600° F, held 1 hr, oil quenched
b. Heated to 1030° F, held 1½ hr, oil quenched
c. Heated to 570° F, held 3 hr, air cooled

Condition C (Hardness R_C 45)

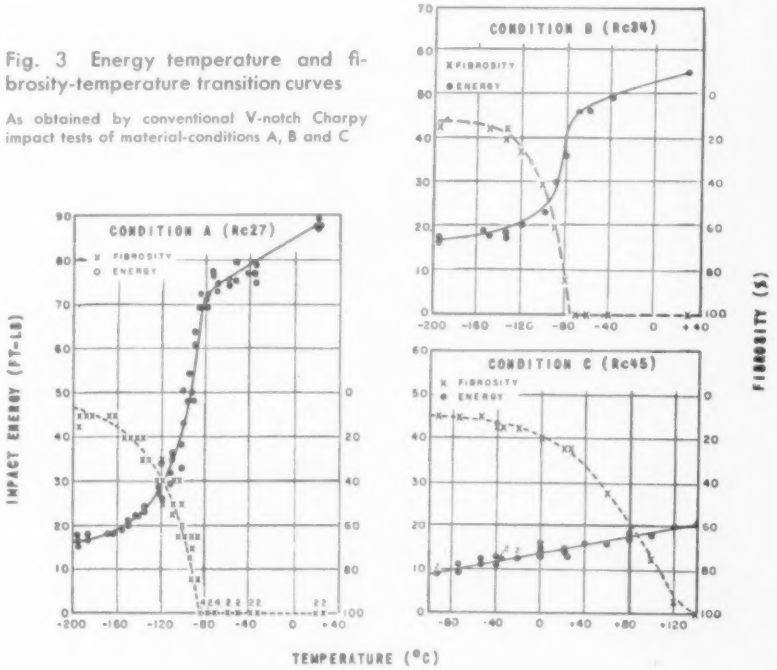
a. Preheated to 1150° F
b. Heated to 1550° F (bumper furnace), held for 15 min, oil quenched
c. Packed in dry ice for 10–12 hr
d. Heated to 780° F, held 2 hr, oil quenched
e. Heated to 375° F, held 3 hr, air cooled

The microstructure produced by the above heat treatments was as follows:

Condition A (R_C 27)—tempered martensite with considerable fine carbide present and some evidence of grain-boundary carbide.

Fig. 3 Energy temperature and fibrosity-temperature transition curves

As obtained by conventional V-notch Charpy impact tests of material-conditions A, B and C



Condition B (R_C 34)—tempered martensite with only a small amount of carbide present, mostly around the grain boundaries; the structure showed evidence of acicularity.

Condition C (R_C 45)—tempered martensite with only a trace of fine carbide; the structure was acicular.

Figure 3 presents the transition curves as obtained by conventional testing procedure for material-conditions A, B and C.* From these curves it may be noted that there is very little difference indicated between material-conditions A and B except in the energy level corresponding to the upper portions of the energy-temperature curves. Material-condition C, on the other hand, is indicated to be relatively notch-sensitive with no abrupt transition from high to low energy values.

Test Methods

The proposed variation in low-blow technique consisted of three steps. First, the energy to initiate cracking was determined; second, the effect of temperature (in the ductile-fracture range) on the incidence and extent of initial cracking was investigated; and third, the onset of brittle fracture was determined by noting the highest temperature at which either the crack-initiating low blow resulted in complete fracture or the low-blow-initiated crack propagated under a second blow without evidence of plastic-deformation work.

To determine the crack-initiating energy level, specimens were delivered a variety of low blows with one blow to a specimen. After delivering a low blow, a drop of india ink containing a wetting agent was deposited in the Charpy V notch of those specimens which did not fracture under the initial blow. By action of the wetting agent and capillarity, the ink flowed into the crack, if present, staining the crack surfaces black. The test specimens were then fractured by means of a full blow of the impact-machine pendulum. Examination of the fracture surfaces for the presence of staining established the crack-initiating energy level for the materials under investigation.

Attention is invited to the fact that the distinction between the crack-initiation and crack-propagation stages of the fracture process was less precise than the author would have liked. This was dictated by the practical difficulty of distinguishing between the various stages of the crack-initiation process. It was found (Figs. 4, 5 and 6) that in the first stage, the initiating crack consisted of shear with so little separation of the fracture surfaces that detection by capillary ink staining was not reproducible.† In the second stage of cracking the initiating crack changes direction, extending perpendicular to the principal stress. At this stage, ink staining provided an easy and reproducible method of crack detection. Therefore, for purposes of this investigation, the term "initiating crack" refers to a low-blow induced crack which can be detected by ink staining.

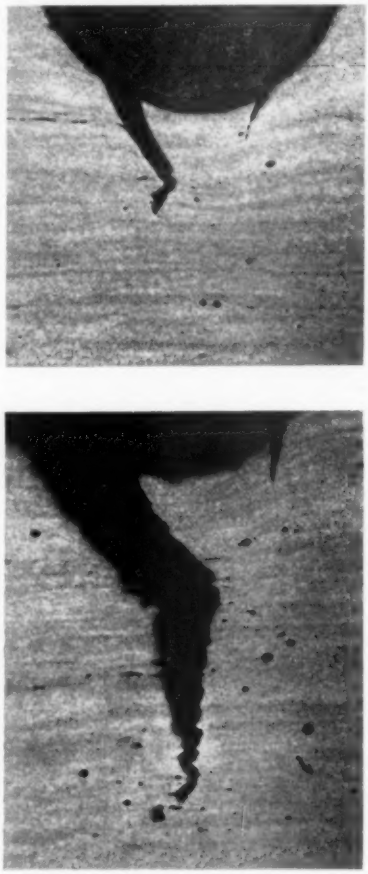


Fig. 4 Initiating cracks in material-condition A (R_C 27)

The upper photomicrograph shows typical cracks produced by a 20 ft-lb low blow at —100° C; the lower, by a 30 ft-lb low blow at —100° C. X 100 (Reduced by 1/3 upon reproduction)

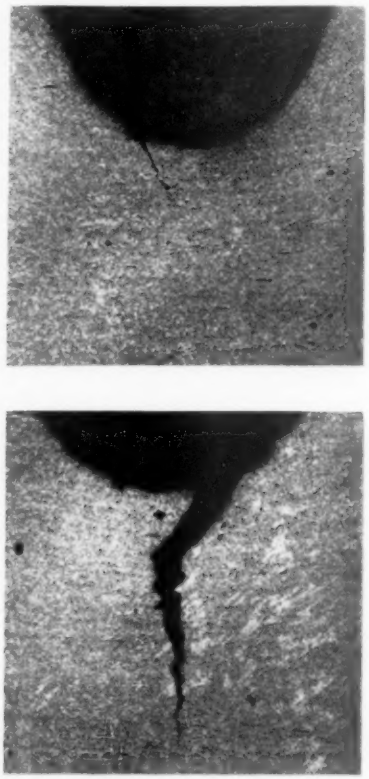


Fig. 5 Initiating cracks in material-condition B (R_C 34)

The upper photomicrograph shows typical cracks produced by a 15-ft-lb low blow at —100° C; the lower, by a 20 ft-lb low blow at —100° C. X100 (Reduced by 1/3 upon reproduction)

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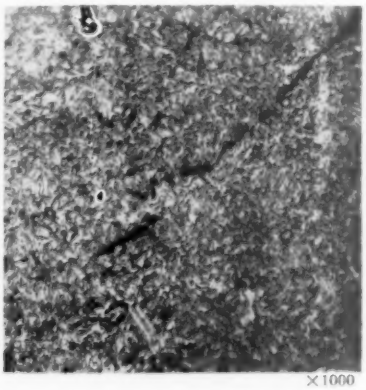


×1000

Fig. 6 Initiating shear crack

Produced by a 12 ft-lb low blow in material-condition C (R_C 45) at room temperature. (Reduced by 1/3 upon reproduction)

* Data supplied through the courtesy of Messrs. T. S. DeSisto and D. E. Driscoll of the Mechanical Metallurgy Branch, Watertown Arsenal Laboratories.

† Even metallographic examination sometimes failed to disclose an extremely-fine initiating shear crack which could be detected only after an external load was applied to the metallographic specimen while being viewed on the microscope (Ref. 8, V. Arnold, unpublished study).

−80° C −120° C −140° C

Fig. 7 Extent of cracking as a function of temperature

The depth of the initiating crack produced by a given low blow (30 ft-lb in this illustration) was found to be essentially constant over a wide range of temperature. At −80 and −120° C, the 30 ft-lb blow resulted in ink-stained cracks as illustrated. The cracking shown for −80° C (100% fibrous fracture) is typical for all higher temperatures tested. The −140° C fracture occurred as a result of the initial blow with the initiating fibrous crack approximately the same depth as ink-stained cracks at −80° and −120° C

Using the crack-initiating low blow, specimens were then tested with a full-energy blow over a wide range of temperature producing ductile fracture. To control the extent of possible strain aging, the time between delivering the blow and subsequent fracturing of the test specimen was held to 24 hr plus or minus 8 hr. Both the low blow and final blow were delivered at the same temperature. The effect of testing temperature on the incidence and extent of low-blow cracking was noted by observing the ink staining on the crack surfaces after such specimens were fractured. In addition to the presence of cracking, the following data were recorded: (a) magnitude of low blow,* (b) temperature of test specimen, (c) lateral expansion produced by the low blow, (d) lateral expansion in the fractured specimen,† and (e) energy absorbed in the fracturing blow.

To resolve questions on the effect of deflection velocity, a smaller hammer was attached to the impact-machine pendulum (15-lb in lieu of the standard 60-lb hammer). Thus, at a given energy level, the smaller hammer raised to a greater height provided a higher hammer velocity. Tests were also conducted using a drop-weight machine, which made it possible to evaluate the crack-initiating energy level over a somewhat wider range of deflection velocities.

Discussion of Results

The Initiating Crack

In all three material conditions (R_C 27, 34 and 45) initial cracking appeared to occur as a result of the shear stress at the free surface of the V notch (Figs. 4, 5 and 6). Cracking was observed to occur in two stages. Initially, the shear crack occurred at approximately 45° to the centerline and at either side of the apex of the machined notch, i.e., on a trajectory of shear stress. After progressing a short distance, the shear crack changed direction to propagate normal to the longitudinal stress. The extension of the shear crack in a direction perpendicular to the principal stress is the second stage of the fracture process. These two stages of cracking are hereinafter referred to as the shear and fibrous portions of the initiating crack. Except for direction, there was very little difference between the shear and fibrous portions of the initiating crack when viewed in cross section under the microscope. The shear crack in fact had the appearance of discontinuous cleavage at high magnification (see Fig. 6), and in some instances very much resembled portions of the fibrous crack. However, when viewed in the fracture surface of a broken test specimen, the two portions of the initiating crack were easily distinguished because of the notably smooth appearance of the shear. In material-conditions A and B, both the shear and fibrous portions of the initiating crack were distinctly visible in the fracture surface of broken test specimens at all temperatures down to and including the brittle-fracture transition temperature (Fig. 7). In material-condition C, on the other hand, the fibrous portion of the initiating crack disappeared at low testing temperature leaving only the shear portion in evidence.

Because of the extreme fineness and sometimes discontinuous nature of the shear crack, detection by means of ink staining at the first stage of crack initiation was found to be uncertain. However, once the initiating crack changed direction and became fibrous, ink staining was found to be both a reproducible and expeditious method of crack detection.

The Crack-Initiating Energy Level

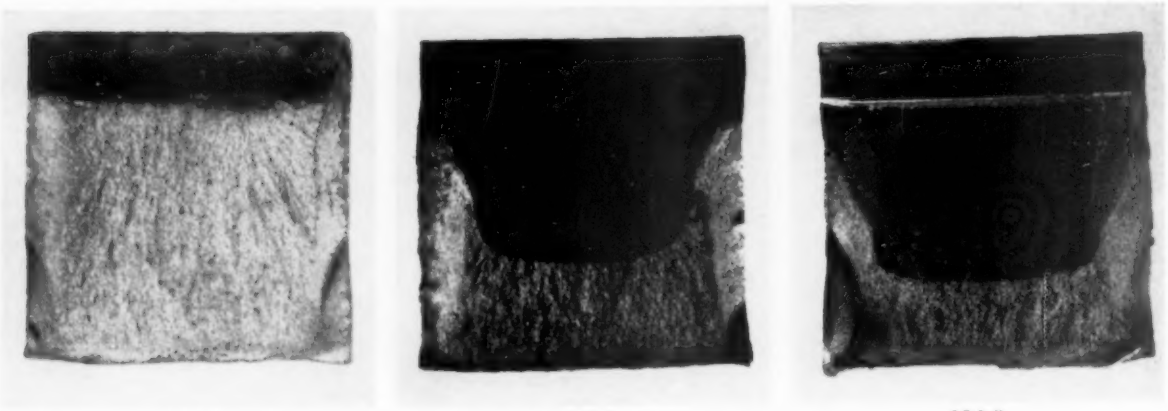
In the case of the material in condition A (R_C 27) a low blow of 15 or 20 ft-lb produced no cracking as determined by staining. With a 25 ft-lb blow, however, stained shear cracks developed at the apex of the V notch. At 30 and 40 ft-lb, cracks were a combination of shear and fibrous fracture. The extent of the initiating fibrous crack as produced by a given low-blow energy level was found to be largely independent of temperature over a wide range (Fig. 7).

In the case of material-condition B (R_C 34), a room-temperature low blow of 15 ft-lb produced no cracking as determined by staining. With a 20 ft-lb blow, however, a stained fibrous crack was observed. At 25 and 30 ft-lb, cracking became progressively deeper. Again the extent of the initiating fibrous crack was found to be largely independent of temperature over a wide range.

In the case of material-condition C (R_C 45), a room-temperature low blow of 10 ft-lb produced no cracking as determined by staining. With a 12.5 ft-lb blow, a stained shear crack was observed. With 15 ft-lb blow, specimens fractured with an energy absorption of 13.5 ft-lb. Subsequent tests to determine the crack-initiating energy level were conducted at +120° C. At this temperature, a 13 ft-lb low blow was found to produce a stained shear crack (Fig. 8). Low blows of 14 and 15 ft-lb, on the other hand,

* When the low blow was sufficient to cause fracture, the value of energy absorbed in fracturing the specimen was recorded.

† By subtracting the lateral expansion produced by the low blow from the total expansion occurring in the fractured test specimen, a measure of the plastic-deformation work required to propagate the initiating crack was determined.



13 ft-lb 14 ft-lb 15 ft-lb

Fig. 8 Extent of cracking as a function of energy in material-condition C (R_C 45)

Unlike material-conditions A and B, a small increase in the energy of low blow caused a marked increase in the depth of the low-blow induced crack (+120° C)

caused a marked increase in the depth of the low-blow-induced crack.

In all three material conditions, the initial cracking occurred on a shear-stress trajectory, progressed for a short distance under the notch, and then changed direction under action of the principal tensile stress to form a fibrous crack. Based on the presence of a fibrous crack as defined heretofore, the approximate crack-initiating energy levels (and attendant deflection rates) were as follows:

Material condition	*Energy (ft-lb)*	*Velocity (ft/sec)*
A (R_C 27)	30	5.7
B (R_C 34)	20	4.6
C (R_C 45)	13	3.8

Effect of Velocity

Because the low-blow technique introduces a variable deflection rate, a check was made as to whether there was a velocity effect in the case of material-conditions A and B. Therefore, the 60-lb pendulum hammer was replaced with a 15-lb hammer; thus, for a given low-energy blow, the 15-lb hammer, raised to a greater height, increased the striking velocity by a factor of two. In material-condition A (R_C 27), the energy level corresponding to initiation of a fibrous crack was the same for both hammers (30 ft-lb at 5.7 ft/sec with the 60-lb hammer and 11.4 ft/sec with the 15-lb hammer). Results in material-condition B (R_C 34) using the 15-lb hammer were anomalous in that slightly less energy was required to initiate fibrous cracking with a 60-lb hammer (20 ft-lb at 4.6 ft/sec) than with a 15-lb hammer (25 ft-lb at 10.4 ft/sec).

The expected effect (if any) of increased deflection rate was to produce cracking at a lower energy level. To resolve the anomalous behavior in condition B and to obtain a wider range of velocity, drop-weight tests were conducted. The results confirmed the crack-initiation energy level obtained with the standard 60-lb hammer. Moreover, variations in drop-weight velocity between 4 and 16 ft/sec had no effect on the energy required to initiate cracking. The anomalous behavior with the 15-lb hammer was attributed to vibration losses.*

Effect of a Crack on Transition Behavior

A previous investigation by Zeno and Low[7] compared the performance of standard V-notched Charpy specimens with Charpys containing a shallow fatigue crack at the bottom of the V notch. The latter were designated by the investigators as V-notch Charpy bars with an "infinitely" sharp notch. The sharp notch was introduced by subjecting finish-machined V-notch Charpy bars to constant-force fatigue until a shallow fatigue crack of controlled depth (0.010 to 0.019 in.) was produced at the apex of the machined V notch. Transition curves were obtained by standard testing procedures. Comparing the relative positions of the transition curves for standard V-notch Charpys and V-notch Charpy bars with a fatigue crack (Fig. 9), lead to the conclusion that the standard V-notch Charpy specimen approaches very closely the most severe conditions of strain rate and notch severity which may be achieved in this size specimen.

Thus, although a preliminary crack-initiating low blow results in a new depth and radius of notch, the findings of Zeno and Low suggest that transition behavior as indicated by energy-temperature transition curves may not be materially affected.

Effect of a Crack-Initiating Blow on Transition Behavior

In an earlier study of transition behavior in V-notch Charpy slow-bend tests (see Ref. 2), brittle fracture was distinguished from ductile fracture by means of a "self-propagating-crack" concept. Transition temperature in slow-bend tests was defined as the highest temperature resulting in a sudden and complete fracture at maximum load (the point on the load-deflection diagram at which the initiating crack, having extended laterally to the sides of the test specimen, propagated in the thickness direction). A crack which propagated suddenly and continuously at maximum load was referred to as "self propagating," i.e., it propagated under action of elastic-stress energy alone rather than as a result of plastic-deformation work.

It was the intent of the tests reported herein to apply the "self-propagating-crack" concept to V-notch impact testing by noting the highest temperature at which specimens failed under a crack-initiating low blow. In view of the fact that the low blow consisted of the minimum energy required to ini-

* In a study of the influence of pendulum flexibilities on impact-energy measurements, BLUHM has shown that energy lost by vibration in the impact machine pendulum can give rise to a significant error in impact test results.[8] The study was prompted by the observation that material-condition C (R_C 45) was found to fracture with remarkable and unfailing reproducibility in one pendulum-type machine having a capacity of 217 ft-lb (16.8 ft/sec) registering an energy absorption of 13 ft-lb and, yet, with the same reproducibility, fail to break in a second machine having a capacity of 16 ft-lb (11 ft-sec). To demonstrate the absence of a significant strain-rate effect, a series of impact tests was conducted using a drop-weight type machine. The rigid masses were machined to weights corresponding to those of the pendulum machines of 16 and 217 ft-lb capacities. The weights were dropped from heights to provide the same energy and impact velocity levels as the pendulum machines. Both drop-weights (217 ft-lb capacity at 16.8 ft/sec and 16 ft-lb capacity at 11 ft/sec) broke the test specimens (at room temperature) when the weight elevation was such as to provide 13 ft-lb of available energy, but *did not* fracture the specimen when the weight elevation corresponded to 12 ft-lb. From these tests it was proposed that variations in impact velocity in the range investigated had little or no effect, and that flexibility "softness" of the 16 ft-lb capacity impact machine was the primary factor in producing the anomalous effect.

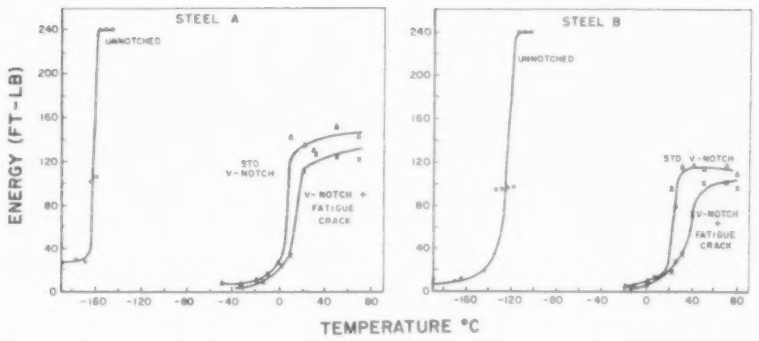


Fig. 9 Energy-transition curves from average impact values

The presence of a natural crack at the apex of the machined Charpy V-notch is shown to have little effect on the transition curve

tiate (ink-stained) cracking, it is hypothesized that when fracture occurred under the initial blow, the energy of low blow was largely dissipated as plastic-deformation work necessary to initiation of the crack, and therefore propagation of the crack was accomplished by action of the elastic-stress energy surrounding the crack.

Figure 10 presents the energy-temperature transition curve for material-condition A specimens prestrained with 20 and 30 ft-lb blows using both 15- and 60-lb hammers. The energy-to-fracture plotted in the ordinate is the energy absorbed in the second full-capacity blow. Thus, when the specimens fractured under the first blow, the data were plotted on the abscissa, indicating zero energy-to-fracture for a second blow. At temperatures producing crystallinity in the fracture (below −80° C) with the exception of the data from specimens which fractured under an initial low blow, energy-to-fracture values fell on a single curve. A similar behavior was noted in the case of material-conditions B and C (Fig. 11). The highest temperatures permitting the formation of a self-propagating crack were as follows:

Condition	*Temperature* (° C)
A(R_C 27)	−120
B(R_C 34)	−120
C(R_C 45)	+ 25

The fact that low-energy blows were absorbed without causing fracture at temperatures at which conventional full-capacity blows produced fracture with less absorption of energy than that delivered in the low blow, points to a possible defect in the low-blow technique when *energy* is used as a performance criterion. For example, material-condition A did not fracture at temperatures down to −196° C when subjected to a 20 ft-lb blow; whereas, the conventional transition curve indicates that at −196° C fracture should have occurred at approximately 17 ft-lb. Moreover, the conventional transition curve indicates that at −140° C a 22 ft-lb blow should have been sufficient to cause fracture; whereas, four out of the eight specimens delivered a 30 ft-lb blow at −140° C did not fracture. Similar behavior was observed in the case of material-conditions B and C (Fig. 11). These discrepancies are attributed to the fact that certain portions of the kinetic energy in the pendulum were not effective in producing fracture, such as the elastic-stress energy developed in the specimen at the points of support and in the anvil and hammer upon impact, the energy lost as a result of brinelling of the test specimen, rebound of the pendulum, vibration in the pendulum, friction, etc. Such energy losses provide an explanation for the fact that the sum of the multiple-blow energies (low-blow energy plus the energy-to-fracture under a second blow) was generally greater than the energy absorbed in fracturing a test specimen with a single full-capacity blow (Fig. 12). Thus, only part of the energy in the impact-machine pendulum is available for (1) doing plastic-deformation work and (2) developing elastic-stress energy in the test specimen in or near the path of fracture.

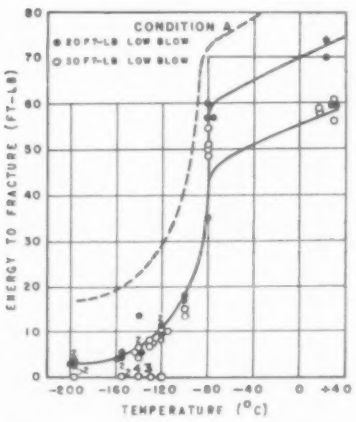
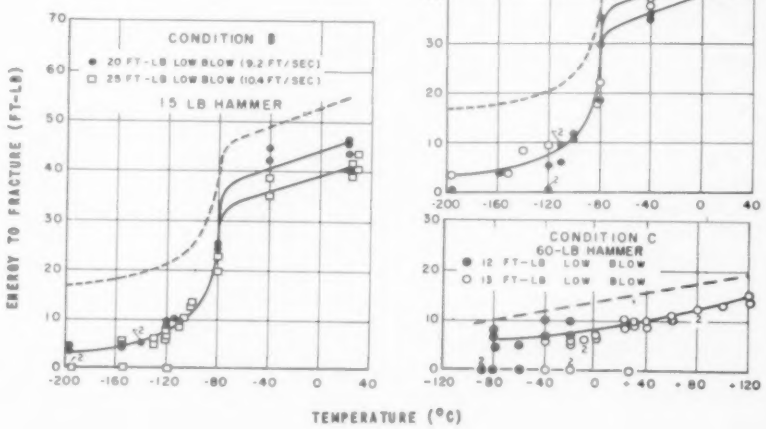


Fig. 10 Effect of an initial low blow on transition behavior in material-condition A

The ordinate is energy absorbed in the second blow; thus, data from specimens which fractured under the initial blow are plotted on the abscissa. The dash curve is the conventional (single-blow) transition curve from Fig. 3

Fig. 11 Effect of an initial low blow on transition behavior in material-conditions B and C

The dash curve is the conventional (single-blow) transition curve from Fig. 3



Lateral Expansion as a Measure of the Plastic-Deformation Work Required to Propagate the Initiating Crack

By measuring the lateral expansion occurring in the test specimen after the initial blow and again after the fracturing blow, the difference provides a measure of the plastic-deformation work required to propagate the initiating crack. When the deformation as measured in the fractured test specimen shows no increase over that measured after the low blow, the plastic-deformation work to propagate the initiating crack is considered to be negligible. From Fig. 13, the highest temperature producing brittle fracture was −130° C in material-condition A, −110° C in B, and +25° C in C. Separate plots for each of the different low-blow energies (20 and 30 ft-lb for A and 15, 20, and 25 ft-lb for B) and different deflection velocities (15 and 60-lb hammers to produce a given low-blow) indicated that variations in the magnitude and velocity of the initial low blow within the ranges investigated had no significant effect on the crack-propagation stage of fracture.

Multiple Low Blows to Simulate Cyclic Loading

In a recent discussion of the brittle-fracture problem,[8] Robertson has pointed out that a ship "—which broke in two at dock—led to the realization that such fractures must not be attributed solely to high nominal stress values likely during storms and certainly not to general yield in the material prior to fracture, for the agreed nominal stress in the fractured plates was of the order of only 5 tons/sq in." The fact that several catastrophic service failures have occurred which appear to have involved little or no plastic deformation has been of prime interest to many investigators. Orowan, for example, has pointed out that in laboratory experiments with ductile steel, brittle fracture is initiated by large deformations producing strong plastic constraint and usually some fibrous cracking before cleavage cracking can start; whereas, many service fractures seem to start without significant plastic deformation in spite of static loading.[9]

Certainly at a nominal stress of 10,000 to 15,000 psi, general yielding would not be expected in ship steel. However, at points of stress concentration the yield strength may be exceeded at low nominal stress values. Moreover, strains caused by prior load cycles may have an influence on subsequent fracture. It is suggested by the author that due to the cyclic nature of most service, plastic deformation and macro-cracking may occur in one cycle, and then in a subsequent cycle involving a low value of nominal stress, be followed by catastrophic brittle fracture. For

Fig. 12 Transition behavior in material-conditions A, B and C as indicated by the sum of the low-blow energy and the energy-to-fracture

The dash curve is the conventional (single-blow) transition curve from Fig. 3

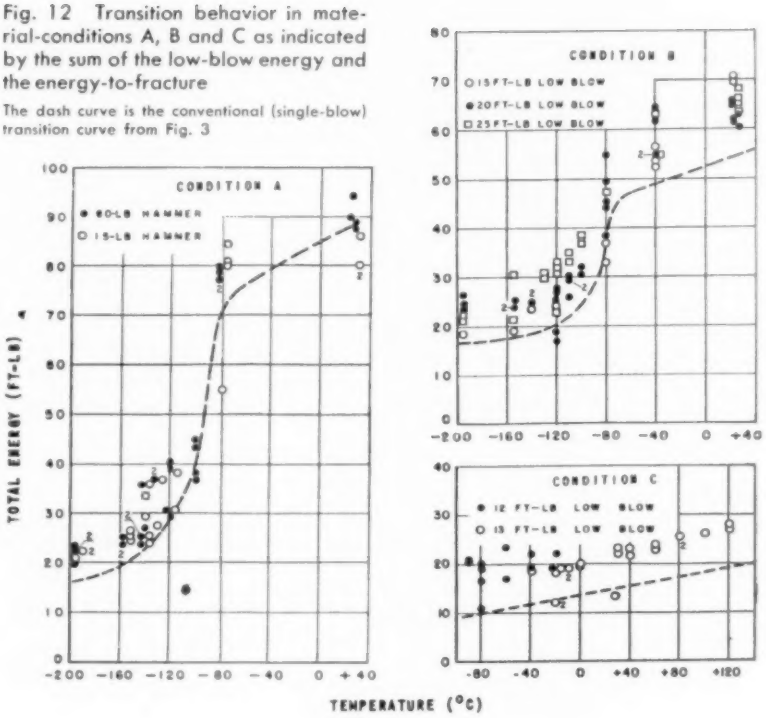
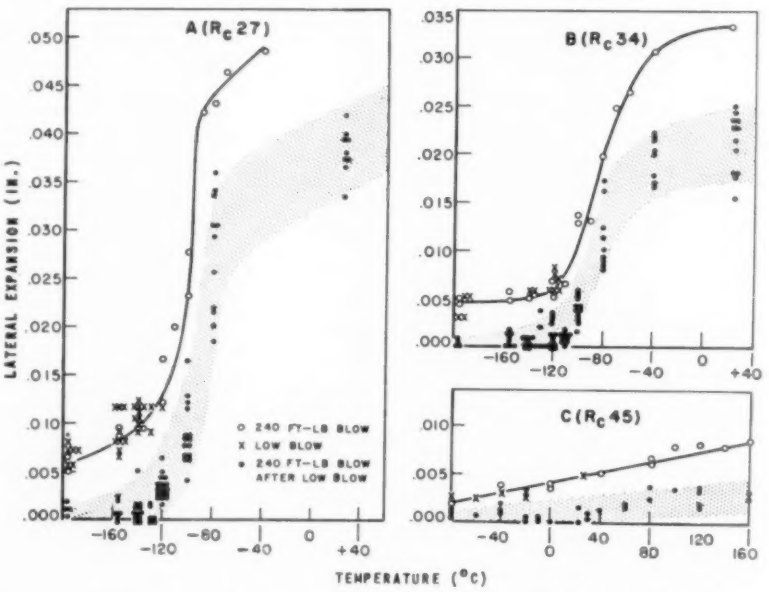


Fig. 13 Deformation-temperature transition curves for 4340 steel at three hardness levels

When the deformation (lateral expansion) as measured in a fractured test specimen (●) shows no increase over that measured after the initial blow, the data are plotted on the abscissa (zero deformation) and fracture is considered to be brittle. The data plotted as (o) and (x) represent total deformation in that the lateral expansion was measured in specimens which fractured under a single blow



example, a ship may be subjected to a storm at sea, return to port intact, and then having previously suffered plastic deformation at points of stress concentration, experience brittle fracture as a result of stresses developing from a sudden drop in temperature or shift in cargo.

An obvious question arising from this discussion concerns the effect of a succession of low blows (instead of a single low blow followed by a full-capacity blow as previously investigated). To determine the effect of multiple low blows, Charpy specimens were delivered initial blows both above and below the crack-initiating energy level, followed by a succession of 10 ft-lb blows to fracture. Tests were conducted on material-condition A at −100 and −140° C. The temperatures of −100 and −140° C were selected to bracket the brittle-fracture transition temperature. At −100° C, material-condition A withstood several low blows before fracturing, with each blow producing additional lateral expansion (Table 1). At −140° C, the material was not sufficiently ductile to withstand even one 10 ft-lb capacity blow subsequent to the initial blow; crack propagation occurred without measurable plastic-deformation work.

Table 1—Material Condition A (R_c 27)

Low blow (ft-lb)	*Lateral expansion (in.) (width)*	*(increment)*
Multiple Low Blows at −100° C		
30	0.4080	0.0135
10	0.4130	0.0050
10*	0.4135	0.0005
* fractured, 5.5 ft-lb absorbed		
30	0.4075	0.0130
10	0.4130	0.0055
10*	0.4145	0.0015
* fractured, 6.5 ft-lb absorbed		
30	0.4090	0.0145
10	0.4110	0.0020
10	0.4160	0.0050
10*	0.4180	0.0020
* fractured, 9.0 ft-lb absorbed		
20	0.4025	0.0080
10	0.4055	0.0030
10	0.4110	0.0055
10*	0.4095	0.0000
* fractured, 4.0 ft-lb absorbed		
20	0.4020	0.0075
10	0.4040	0.0020
10	0.4070	0.0030
10	0.4110	0.0040
10*	0.4150	0.0040
* fractured, 8.0 ft-lb absorbed		
Multiple Low Blows at −140°C		
20	0.4015	0.0070
10*	0.4010	0.0000
* fractured, 3.5 ft-lb absorbed		
20	0.4020	0.0075
10*	0.4015	0.0000
* fractured, 4.0 ft-lb absorbed		
20	0.4005	0.0060
10*	0.3995	0.0000
* fractured, 4.0 ft-lb absorbed		

If an analogy can be made between performance in the V-notch Charpy specimen and a point of stress concentration in a structure, the above results provide an explanation for service failures which have occurred at or below the design working stress. Explanation is based on the assumption that at some prior load cycle, sufficient strain occurred at a point of stress concentration to initiate microcracking. Subsequent cycles, even at loads well below the working stress, may then cause either progressive damage or sudden brittle crack propagation.

Summary Discussion

Based upon a single heat of AISI 4340 steel, quenched and tempered to three hardness (strength) levels, the following behavior has been observed in V-notch Charpy specimens subjected to low energy blows:

1. The initial cracking as produced by a low-energy blow occurred in the free surface of the machined V notch on a shear stress trajectory.

2. While detection of this initial stage of cracking was difficult without metallographic examination, the second stage of cracking was easily and reproducibly determined by ink staining. In the second stage, the initiating shear crack changed direction to propagate perpendicular to the principal stress, and appeared in the fracture surface as typically fibrous.

3. The extent and ductile nature of the initiating crack produced by a given magnitude of low blow was essentially constant over a wide range of temperatures extending below the brittle-fracture transition temperature.

4. The variation in deflection rate (approximately 4 to 16 ft sec) introduced by the low-blow technique did not have an appreciable effect on the presence or extent of the initiating crack.

5. Specimens which were prestrained and cracked by low blows of different energy levels and then fractured over a range of testing temperatures by a full 240 ft-lb capacity blow, provided energy-to-fracture data which plotted as a single curve at temperatures producing crystallinity in the fracture surface. Thus, variations in the extent of the initiating crack, from microscopic shear to ink-stained fibrous cracks, had little or no effect on the amount of work necessary to propagate the initiating crack. Temperature was the controlling factor.

6. Using lateral expansion as a measure of plastic-deformation work, it was possible to distinguish between ductile and brittle fracture by measuring the lateral expansion associated with the crack-initiating low blow and then measuring the lateral expansion in the fractured test specimen. If, at the temperature of test, the initiating crack was propagated without measurable plastic-deformation work (no increase in lateral expansion after the initial blow), the fracture was classed as brittle. The highest temperature allowing brittle crack propagation was defined as the transition temperature. If, on the other hand, the crack-initiating low blow completely fractured the test specimen, this too was classed as brittle crack propagation; and the highest temperature permitting complete fracture under the initial low blow was also taken as the transition temperature. The values as obtained by the two methods are listed in the following table:

Condition	*Temperature (° C) (a)**	*(b)†*
A (R_c 27)	−130	−120
B (R_c 34)	−110	−120
C (R_c 45)	+ 25	+ 25

* Brittle fracture under the second (full-capacity) blow.

† Brittle fracture under the initial low blow.

7. Investigation of the effect of multiple low blows offered an explanation for catastrophic service failures which have occurred under conditions of low nominal stress (10,000 to 15,000 psi). Specimens from material-condition A (R_c 27) when subjected to a low blow of 20 ft-lb and subsequently struck a single 10 ft-lb capacity blow, fractured at −140° C with no measurable plastic deformation attending the second blow; whereas, when tested at −100° C, a number of 10 ft-lb blows was required to produce fracture, with plastic-deformation work attending each blow. Thus, an analogy is suggested between performance in the laboratory test specimen and the case of a bridge, ship, or storage tank subjected to a cyclic loading which causes local plastic yielding (at points of stress concentration) and then fractures in a brittle fashion on subsequent load involving low nominal stresses and temperature below the brittle-fracture transition.

Conclusion

An easily executed variation in the standard technique for testing V-notch Charpy impact specimens is presented. The technique permits a separation of the crack-initiation and crack-propagation stages of the fracture process. The differentiation between ductile and brittle fracture is based on the concept that a brittle-fracture crack is propagated by continuous release of the elastic-stress field surrounding the crack, whereas a ductile-fracture crack

requires plastic-deformation work to extend the crack. The measurement of lateral expansion (Poisson effect) provides a sensitive gage of the plastic-deformation work done (1) in crack initiation and (2) in propagation of the initiating crack.

Two approaches appear feasible; both involve the initiation of a crack by means of an initial low-energy blow. One approach determines the highest temperature at which a crack-initiating low blow causes complete fracture of the test specimen, i.e., the initiating crack propagates by continuous release of the elastic-stress field developed by the initial low blow. (In the case of the highly notch-tough conditions A (R_c 27) and B (R_c 34), there is a critical low-blow energy level below which a "self-propagating" crack will not form). The second approach involves the delivery of a crack-initiating low blow followed by a full-capacity fracturing blow, and is based on the concept that when the fracturing blow produces no measurable increase in lateral expansion, the plastic-deformation work required to extend the initiating crack is essentially zero; such a fracture is therefore considered brittle. The highest temperature permitting crack propagation without plastic-deformation work to extend the crack, is the brittle-fracture transition temperature. In that both approaches are based on the same criterion of brittle fracture, the transition temperatures determined by the two methods are, for all practical purposes, the same.

If, on the other hand, an arbitrary energy level, for example, 20 ft-lb is used in determining transition temperature (column (c) of the following table), the temperatures may be expected to be different from those determined on the basis of the brittle-fracture criterion. It will be noted that the transition temperatures for material-conditions A and C as determined by the 20 ft-lb energy level method do not check those obtained by the brittle-fracture criterion; whereas, the transition temperatures for material-condition B do check. It is believed that the reason for the latter is that the 20 ft-lb level in the case of material-condition B is approximately the crack-initiating energy level for that condition. If the transition temperatures are determined for each material condition on the basis of the minimum energy to initiate cracking (i.e., A 30 ft-lb, B 20 ft-lb, and C 13 ft-lb), the transition temperatures so obtained are approximately the same as those obtained by the brittle-fracture criterion.

	Transition Temperature		
		Temperature (° C)	
AISI 4340 condition	*(a)**	*(b)†*	*(c)‡*
A (R_c 27)	−130	−120	−150
B (R_c 34)	−110	−120	−120
C (R_c 45)	+ 25	+ 25	+120

* Brittle fracture under the second (full-capacity) blow.
† Brittle fracture under the initial low blow.
‡ Transition temperatures based on a 20 ft-lb energy level.

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RELATION OF CHARPY IMPACT PROPERTIES TO MICROSTRUCTURE OF THREE SHIP STEELS

Investigation covers the extent to which the fracture properties of three ship steels can be accounted for in terms of gross microstructural parameters, the necessary range of microstructures typifying those found in commercial plates and being obtained by simple heat treatments

BY W. S. OWEN, D. H. WHITMORE, MORRIS COHEN AND B. L. AVERBACH

ABSTRACT. This paper describes the relationships between the significant microstructural parameters, as observed with the optical microscope, and the brittle behavior of three ship plates, a killed (ABS Class C), semikilled (ABS Class B) and a rimming (project E) steel. The ferrite-pearlite aggregate was varied systematically by means of annealing and normalizing treatments, and correlations were obtained between several measured microstructural parameters and the Charpy V-notch transition temperature.

In annealed structures, the transition temperature increases with ferrite grain size, pearlite patch size, and the related parameter, austenite grain size, the correlation being strongest with ferrite grain size. Differences between the C and B series can be accounted for by differences in the ferrite grain growth characteristics, but other factors are operative in the E steel.

In the normalized series, the variations of transition temperature cannot be explained in terms of the above metallographic parameters. It is concluded that cooling rate, and probably compositional differences, can produce effects which influence the transition temperature but which cannot be measured by optical microscopy. Evidently, submicroscopic phenomena are of major importance.

Introduction

The effects on the Charpy transition temperature produced by changes in microstructural features of mild steel have been studied extensively at the Naval Research Laboratory, Battelle, and elsewhere.[1] Most of this work has been concerned either with laboratory melts or selected steels especially treated to accentuate the structural feature being examined. The object of the present investigation was to determine to what extent the fracture properties of three ship steels could be accounted for in terms of gross microstructural parameters, the necessary range of microstructures typifying those found in commercial plates and being obtained by simple heat treatments.

In the past, a large number of microstructural variables have been suggested as potent factors in the fracture process. However, many of these are of negligible importance in the range of structures under consideration. Allen, Rees, Hopkins and Tipler,[2] working with high-purity iron-carbon alloys, Matton-Sjoberg and Lindblom[3] with steels containing less than 0.05% carbon, and Danko and Stout[4] with 1025 steel slowly cooled from 1300° C have all shown that cleavage fracture can be initiated at a ferrite grain boundary or a ferrite-pearlite interface. However, an extensive examination of the location of microcracks and secondary cracks in the present ship steels failed to reveal evidence of initiation at these interfaces.

Another aspect of the microstructure which has received detailed consideration is the carbide morphology. Some recent investigations[5-7] have been directed at the relationship between pearlite spacing and transition temperature. Although there is some disagreement about the sign of the change in Charpy transition with increasing pearlite spacing, it is evident that, within the range of structure here under discussion, the effect is negligible. The influence of carbide precipitation produced by subcritical heat treatments has been investigated by Brick[8, 9] in high-purity iron-carbon alloys and by Josefsson[10] in commercial grades of low-carbon steel. While in very low-carbon alloys spectacular changes in transition temperature with changes in the extent and distribution of precipitated carbide were revealed, the effects were not detectable when the carbon content was greater than about 0.05%. Thus, no direct effects due to this cause were anticipated in the ship steels.

It is well known that ferrite grain size exerts a marked influence on the ductile-brittle transition as established by notch-bar tests.[11, 13] Work at Battelle,[1c] utilizing a limited range of heat treatments and structures, has demonstrated that linear relationships exist between ferrite grain size and Charpy-keyhole transition temperature (at the 12 or 20 ft-lb level) for a low-carbon steel and several semikilled mild steels. Similar results have been obtained by Vanderbeck.[1d]

In the current work the standard V-notch Charpy technique was used. The relationships between the transition temperature and the microscopic parameters, reflecting the size and distribution of both the ferrite and pearlite volumes, were explored over a range of deoxidation practices, austenitizing temperatures and cooling rates. Since the specimens were taken from three different large-scale heats, a compositional variable was also present.

Experimental Methods

The three steels were supplied in the form of hot-rolled plates, 108- x 72- x 3/4-in., from open-hearth heats manufactured under carefully observed conditions. The killed (ABS Class C) and semikilled (ABS Class B) plates were taken from normal production hull steel manufactured to conform to the 1948 revised specification for ship plate. The rimming steel (project steel E) was made between 1944 and 1946 for experimental purposes, and earlier tests have indicated that it has a greater brittle-fracture tendency than commercial steels of this class. The chemical composition and room temperature mechanical properties of the steels, referred to as C, B and E, are given in Table 1.

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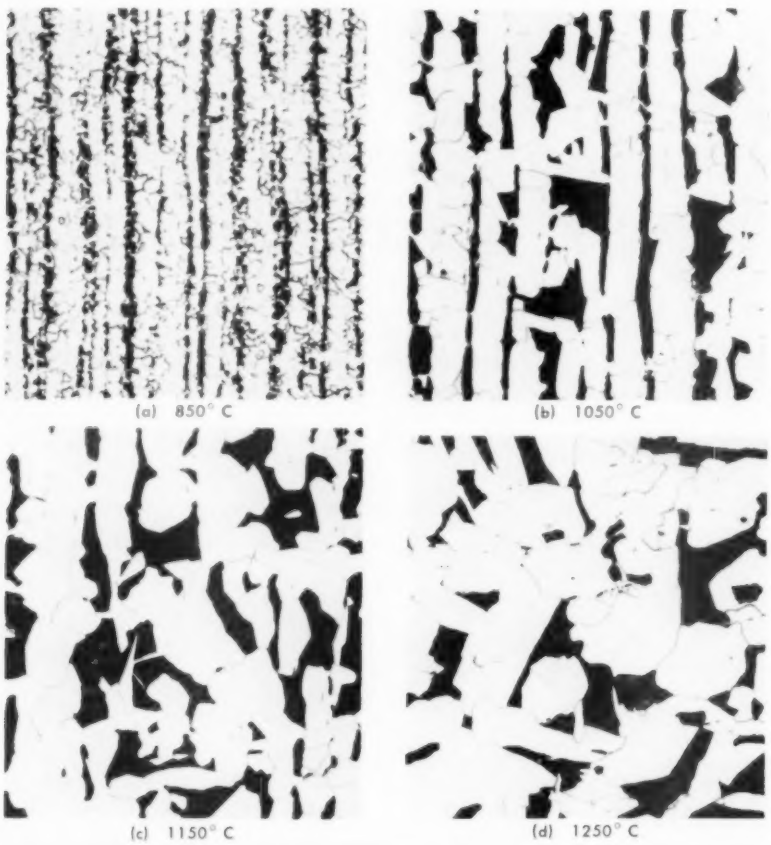


Fig. 1 Microstructure of C steel, furnace-cooled from indicated austenitizing temperatures. Nital etch—transverse section. X 100

Specimens of each steel were austenitized in a purified nitrogen atmosphere at temperatures in the range of 850–1300° C. In one series the austenitizing was followed by air cooling (150° C per min), and in another by cooling in the furnace (1.6° C per min).

The Charpy specimens were cut parallel to the rolling direction with the notch normal to the plate surface. Twenty to thirty specimens were used to obtain the usual energy/temperature curve and the transition temperature was taken at the 10 ft-lb level. In most cases, a more precise value of the 10 ft-lb V-notch transition temperature was obtained by further testing in accordance with a statistical "staircase" method, an additional 20 specimens being tested in a planned sequence of temperatures spaced at 5° C intervals near the transition temperature as indicated by the original energy/temperature curve. The analysis of the data has been discussed in detail elsewhere.[14]

Transverse microspecimens were prepared from Charpy blanks representing each heat treatment. The quantitative metallography was performed on a Hurlbut counter[15] by two observers who were chosen from six on the basis of a latin-square test. The analysis of the data was performed in most cases by the MIT Statistical Service using IBM computing machines.

Experimentally, the following measurements were obtained:

L_F = total ferrite intercept in millimeters
L_P = total pearlite intercept in millimeters
N_F = number of ferrite grains traversed
N_P = number of pearlite "patches" traversed

and from these the appropriate microstructural parameters were computed.

The Ferrite Grain Size, n_V — Number of Ferrite Grains per Unit Volume of Ferrite

Assuming the ferrite grains are Kelvin equi-edged tetrakaidekahedrons which completely fill space,[16, 17]

$$n_V = \frac{0.4263 N_F^3}{L_F^3} \qquad (1)$$

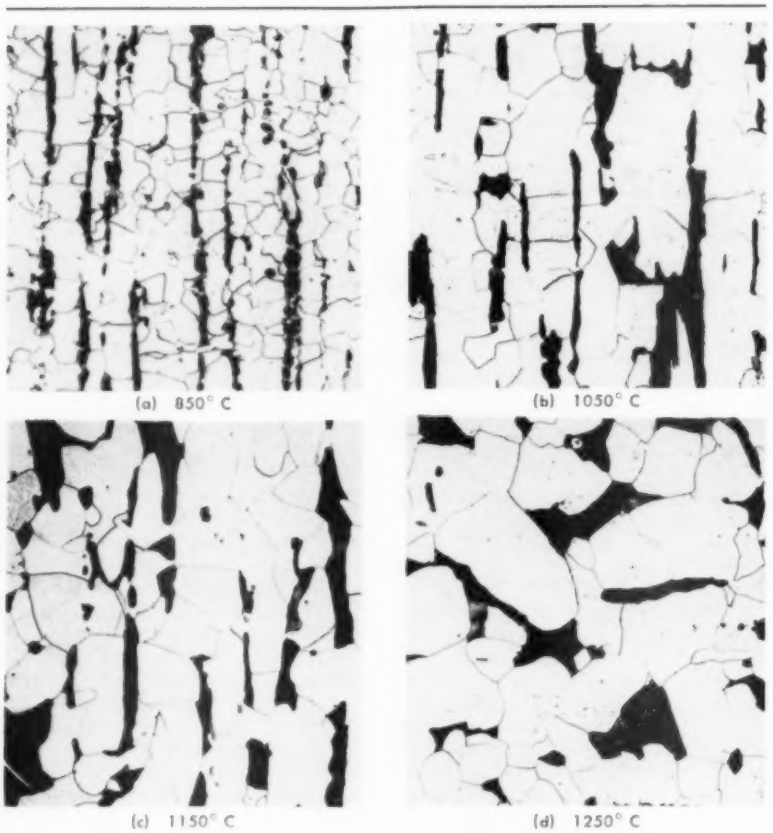


Fig. 2 Microstructure of B steel, furnace-cooled from indicated austenitizing temperatures. Nital etch—transverse section. X 100

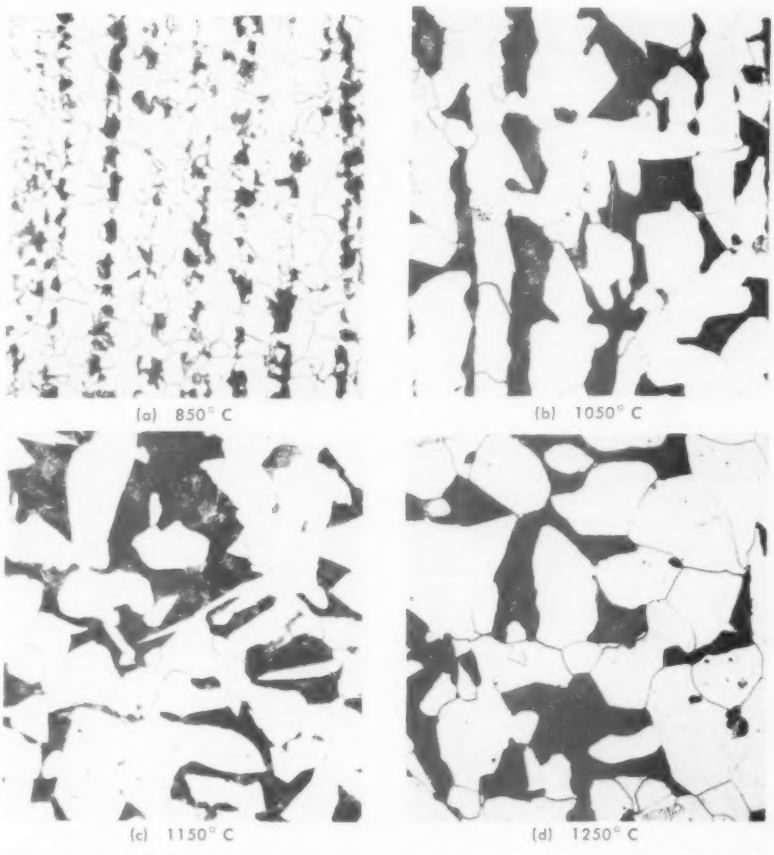


Fig. 3 Microstructure of E steel, furnace-cooled from indicated austenitizing temperatures. Nital etch—transverse section. X 100

Values of n_V (grains per mm^3) are readily converted to ASTM grain size numbers through the tabulation given by Rutherford, *et al.*[15] It should be noted that n_V is the number of ferrite grains per unit volume of *ferrite*. This can be converted to grains per unit volume of steel by multiplying by the volume fraction of ferrite.

The Volume Fraction of Ferrite, V_F, and of Pearlite, V_P

These quantities are given directly by:

$$V_F = \frac{L_F}{L_F + L_P} \qquad (2)$$

$$V_P = \frac{L_P}{L_F + L_P} \qquad (3)$$

The Mean Ferrite Path, α_1, and α_2

The mean ferrite path was expressed in two ways. α_1 is defined as the mean distance between boundaries in the ferrite, as intercepted along a straight line, whether by ferrite-ferrite or ferrite-pearlite boundaries:

$$\alpha_1 = \frac{L_F}{N_F} \qquad (4)$$

α_1 is directly related to the mean grain diameter,[18]

$$d = 1.65\ \alpha_1 \qquad (4a)$$

α_2 is defined as the mean distance in the ferrite as intercepted along a straight line by ferrite-pearlite boundaries (leaving out the ferrite-ferrite boundaries):

$$\alpha_2 = \frac{L_F}{N_P} \qquad (5)$$

The Pearlite Patch Size, β

The patches assumed various irregular shapes. Consequently, the average pearlite linear intercept, β, was considered to be the most appropriate parameter:

$$\beta = \frac{L_P}{N_P} \qquad (6)$$

The austenite grain size was measured by similar methods at the appropriate location in end-quenched bars.

Results

Photomicrographs of transverse sections through representative specimens are shown in Fig. 1–6. In the furnace-cooled series, the austenite and ferrite

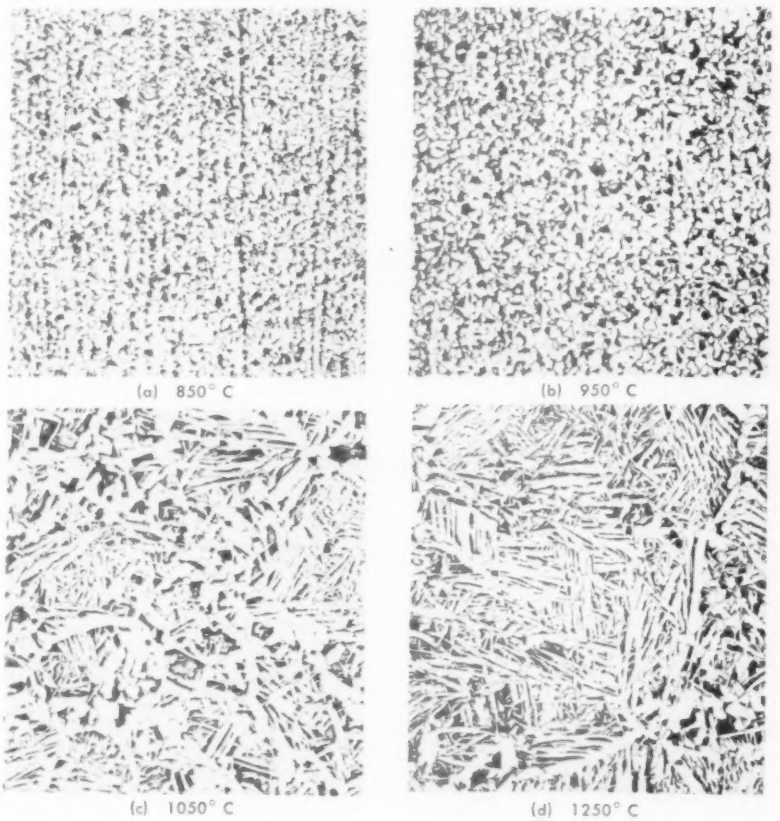
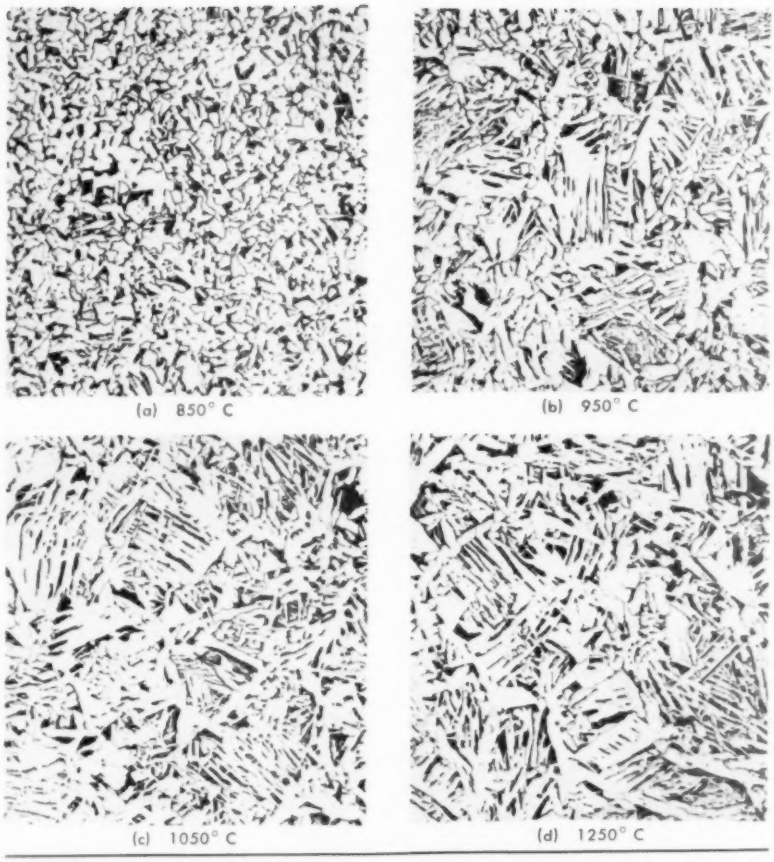


Fig. 4 Microstructure of C steel, air-cooled from indicated temperatures. Nital etch—transverse section. X 100

Fig. 5 Microstructure of B steel, air-cooled from indicated temperatures. Nital etch—transverse section. X 100



grain size increased with austenitizing temperature and the ferrite paths (α_1 and α_2) increased accordingly. At 850° C the C steel had a much finer austenite grain size than the B or E steel. However, all the steels coarsened between 950 and 1050° C, and at higher temperatures, had approximately the same grain size. The ferrite grain size established on furnace-cooling paralleled the austenite grain size.

In general, normalizing refined the structure, yet the microscopic parameters of the air-cooled series were remarkably insensitive to the austenitizing temperature. Widmanstätten structures were formed on air cooling from 1050° C and above. Lower temperatures produced equiaxed ferrite with the exception of B steel austenitized at 950° C which contained some Widmanstätten ferrite.

The measured volume fraction of pearlite indicated a difference in the transformational behavior of the steels. In the C and B steels, air cooling slightly increased the amount of pearlite (Table 2). In contrast, the pearlite fraction in the E steel was increased by as much as a factor of two by altering the cooling rate from furnace to air cooling. Possibly the higher manganese content of the C and B steels rendered them relatively insensitive to cooling rate. This postulation is supported by the observation that raising the manganese content decreases the slope of the proeutectoid ferrite and pearlite C-curves in the isothermal transformation diagrams.[19]

Furnace cooling from an austenitizing temperature in the range of 850–1150° C resulted in a banded structure in all the steels: the effect was most pronounced in the C and B steels.

Microstructure and Charpy Transition Temperature

The 10 ft-lb V-notch Charpy transition temperature is plotted as a function of the austenitizing temperature in Fig. 7. The furnace-cooled B steel data generally lie about 34° C below those of the E steel. When austenitized at 1050° C or higher and furnace cooled, the C and B steel results almost coincide. However, the fine-grained

Fig. 6 Microstructure of E steel, air-cooled from indicated austenitizing temperatures. Nital etch—transverse section. X 100

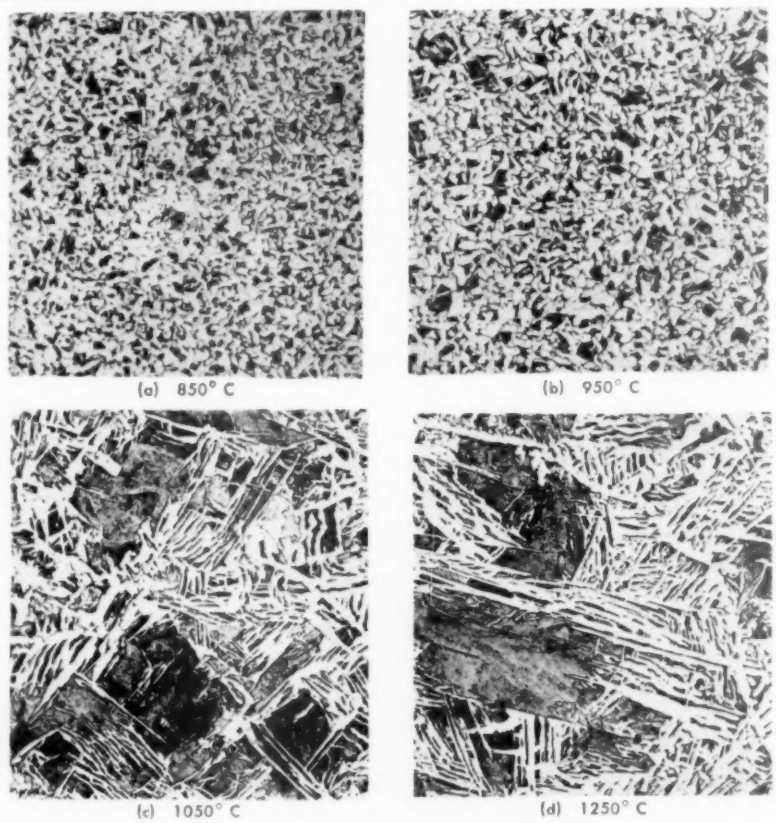


Table 1—Chemical Composition and Engineering Properties of Steels

Designation	*C*	*Mn*	*P*	*S*	*Si*	*Cu*	*Al*
ABS Class C	0.20	0.62	0.014	0.030	0.19	0.27	0.012
ABS Class B	0.16	0.69	0.014	0.028	0.022	0.028	0.042
Project Steel E	0.22	0.36	0.016	0.031	0.002	0.017	0.018

Room-Temperature Mechanical Properties

	Yield point, 10^3 psi		*Elastic limit, 10^3 psi*	*Ultimate tensile strength, 10^3 psi*	*Elongation, %*	*Reduction in area, %*
	Upper	*Lower*				
ABS Class C	48.1	44.3	24.0	68.4	25.2	65.4
ABS Class B	33.0	31.0	22.0	57.2	30.9	58.2
Project Steel E	34.0	33.0	20.0	67.5	27.1	55.0

C steel specimens austenitized below the coarsening temperature (i.e., at 850 and 950° C) had a much lower transition temperature than B steel specimens with the same heat treatment. In all cases, changing from furnace to air cooling decreased the transition temperature. The improvement in the E steel air cooled from 950° C was particularly marked.

When compared on the basis of austenitizing temperature, the Charpy data for the three steels are well separated. To determine whether these differences can be accounted for by differences in the microstructural parameters, the Charpy data are plotted against each of the parameters in turn. Here, the microstructural parameters are those measured perpendicular to the plate surface, that is, in the same direction as the V-notch of the Charpy bar. This selection was suggested by the results of Harris and co-workers[20] who, using low-energy repeated blow tests, showed that the crack initiated near the root of the notch and spread laterally before propagating catastrophically across the specimen. It was found that this method of treating the data gave better correlations than when the microstructural parameters were averaged between the perpendicular and parallel directions; however, the over-all trends were not materially affected.

In Figs. 8-12, the 10 ft-lb Charpy V-notch transition temperature for the furnace-cooled series is seen to increase with n_V, α_1, α_2, β, and the austenite grain size. These trends were expected because the transition temperature and each of the microscopic parameters all increase with austenitizing temperature.

The relationship between the transition temperature and log n_V (or correspondingly the ferrite grain size expressed in ASTM numbers) was found to be linear to a remarkable degree over the whole range of annealing treatments. The empirical regression lines for the furnace-cooled series are shown in Fig. 8. The slopes are 13, 10 and 8° C per ASTM number for the C, B and E steel respectively. Using keyhole Charpy bars the Battelle investigators[16] and Vanderbeck[14] have reported a higher value of 16.7° C per ASTM number for semikilled steel. For killed steel Vanderbeck found a change of 11.1° C per grain size number.

The ferrite parameters n_V and α_1 are explicitly related through equations (1) and (4):

$$\alpha_1 = \frac{0.7527}{n_V^{1/3}} \qquad (7)$$

The curves shown in Fig. 9 were calculated from the regression lines of Fig. 8 and, as expected, they are a good fit to the experimental points. The transition temperature also increased with the parameters α_2 (Fig. 10) and β (Fig. 11), and smooth curves were drawn through the data. However, the relationships are not of a simple form.

The transition temperature of the air-cooled specimens is plotted as a function of the ferrite grain size in Fig. 8. Many of the structures in this series were Widmanstätten and in these cases the ferrite grain size used in the plots is an idealized parameter: here, n_V is the number of ferrite grains per cubic millimeter which would be present in a steel with an equiaxed structure and the same mean ferrite path α_1 as the Widmanstätten structure.

Discussion

It has been suggested[21] that the controlling metallographic factor is the austenite grain size, although no quan-

Table 2—The Volume Percentage of Pearlite in Air and Furnace-Cooled Specimens

Steel	*Austenitizing temperature, ° C*	*Volume percentage of pearlite* — *Furnace cooled*	*Air cooled*
C	850	17.0	18.0
	950	14.7	18.8
	1050	20.0	22.7
	1150	19.8	22.5
	1250	21.0	21.5
B	850	13.9	14.5
	950	14.6	15.2
	1050	14.7	15.8
	1150	17.4	15.9
	1250	16.5	16.9
E	850	17.0	23.0
	950	18.2	27.9
	1050	25.0	36.1
	1150	25.1	48.4
	1250	26.6	51.9

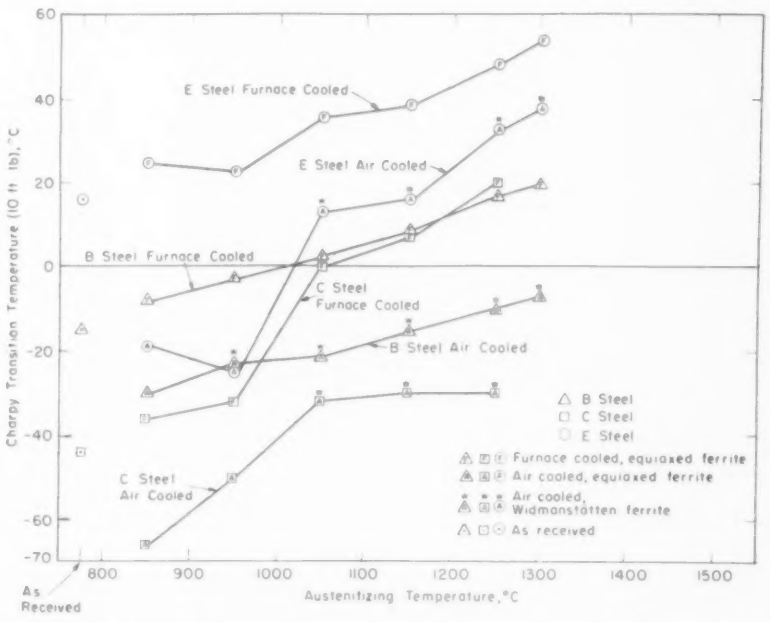


Fig. 7 Relationship between Charpy transition temperature (10 ft-lb level) and the austenitizing temperature

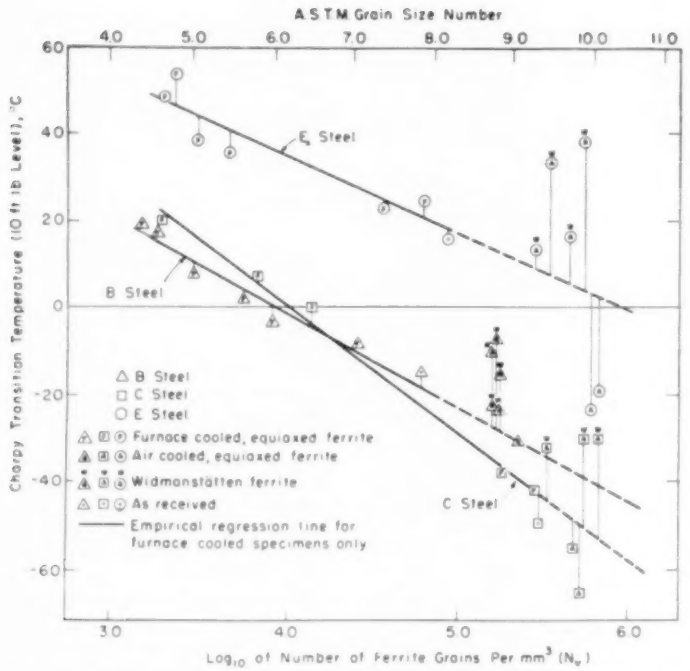


Fig. 8 Relationship between ferrite grain size and Charpy transition temperature (10 ft-lb level)

titative studies of the relationship have been reported. Obviously, austenite cannot have a direct effect, but the austenite grain size could be a composite parameter reflecting the influence of its progenies, ferrite and pearlite. In Fig. 12 the transition temperature is plotted as a function of the logarithm of the number of austenite grains per cubic millimeter, and, thus, the plot is comparable with Fig. 8. The transition temperature increases with increasing austenite grain size in a roughly linear fashion. However, the scatter in the data is appreciably greater than in the corresponding ferrite grain size plot.

The presence of pearlite banding was not an over-riding factor in influencing the transition temperature. Both high- and low-transition temperatures were observed with a given degree of banding (Fig. 13), from which it is inferred that any effect due to banding is masked by other more powerful influences. This also suggests that the parameters α_2 and β, used to measure the banding, are of secondary importance. This view is substantiated by the fact that the transition temperature showed only general trends with changes in these parameters (Figs. 10 and 11) and no consistent functional relationship was found.

Another secondary factor was the volume fraction of pearlite (V_P) which, except for the air-cooled E specimens, was relatively insensitive to the heat treatment (Table 2). The role of pearlite is discussed later.

It appears that the dominant microstructural feature is the ferrite grain size, and hence, n_1 and α_1 are the most suitable parameters with which to describe the Charpy behavior. Log n_1 is preferred because, for the furnace-cooled series, the relationship is linear over a wide range of austenitizing temperatures.

In Fig. 8, all the Charpy data are assembled in terms of the ferrite grain size n_V. Comparing the furnace-cooled (represented by the regression lines) and air-cooled results for any one steel, the following generalizations emerge:

1. In air-cooled specimens with equiaxed ferrite structure, the transition temperature was lower than that of a furnace-cooled specimen of the same grain size. This effect was very pronounced in the rimmed E steel and well defined in the killed C steel. In the semikilled B steel, because of a strong tendency for Widmanstätten structures to form, only one equiaxed air-cooled specimen was obtained (850° C), which showed no improvement in transition temperature other than that produced by the grain refining effect of the faster cooling rate.

2. The transition temperature of an air-cooled specimen with a Widmanstätten structure was higher than that of a furnace-cooled specimen of the equivalent grain size. All three steels showed this effect clearly and to about the same extent.

3. The as-received specimens had roughly the same transition temperatures as those of furnace-cooled specimens of the same grain size.

The difference between air-cooled and furnace-cooled specimens with equiaxed ferrite structures was not due to changes in the pearlite. The volume fractions of pearlite are listed in Table 2. The improvement in fracture properties on air cooling was accompanied by an increase in the amount of pearlite, which should act in the opposite direction. Thus, comparing specimens at

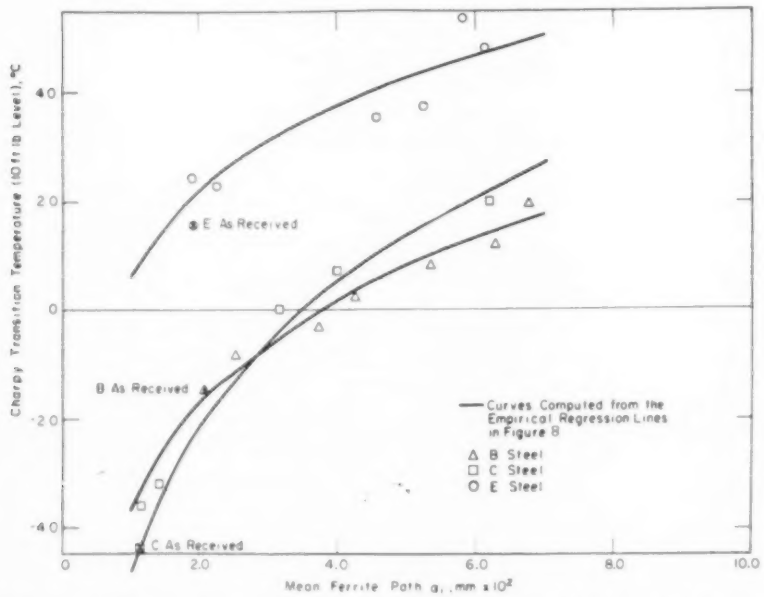


Fig. 9 Charpy transition temperature (10 ft-lb level) as a function of the mean ferrite path α_1. Furnace-cooled series only

the same grain size and percentage pearlite, the decrease in transition temperature on air cooling would be even greater than that indicated by Fig. 8.

The increase in transition temperature with the appearance of Widmanstätten structures was accompanied by an increase in the amount of pearlite. On changing from furnace cooling to air cooling, the volume fraction of pearlite increased markedly in the E steel, slightly in the C steel, and was almost unchanged in the B steel (Table 2). Yet, an increase in transition temperature on changing from equiaxed to Widmanstätten structures cooling was observed in all the steels. Consequently, it appears that the attendant variation of the pearlite fraction was not the primary cause of the increase in transition temperature. Within the range of treatments producing Widmanstätten structures, the microstructural parameters showed very little dependence upon austenitizing temperature, but the variation in transition temperature was appreciable. In part, this may be accounted for by slight changes in the morphology of the Widmanstätten structure which were not reflected in the measured parameters. However, it seems improbable that this is a complete explanation.

In summary, air cooling changes the transition temperature in a way that can be explained only partially by changes in the gross microstructure. Thus, it is concluded that substructural effects are an important feature of this phenomenon. An electrolytic polishing and etching technique, which was developed to reveal substructure in single crystals of ferrite, was tried on a number of air-cooled and furnace-cooled specimens, but the results were inconclusive. Further elucidation of this problem must await the development of new techniques for examining substructure in polycrystalline metals.

The difference in the regression lines for the C and B steel furnace-cooled series is not considered to be significant. Within the limits of experimental error, the two steels display essentially the same variation of transition temperature with ferrite grain size. The lower transition in the C steel specimens austenitized at temperatures below 1050° C can be quantitatively explained in terms of the resulting ferrite grain size which is much finer in the C than the B steel. The propensity of the C steel to form fine-grained structures is also evident in the air-cooled series. The fine grain size is undoubtedly *one* of the factors contributing to the very low transition temperature obtained by air-cooling C steel from 850 or 950° C. Even in the specimens with Widmanstätten structures, the C steel has a finer structure and lower transition temperature than the corresponding B steel specimen.

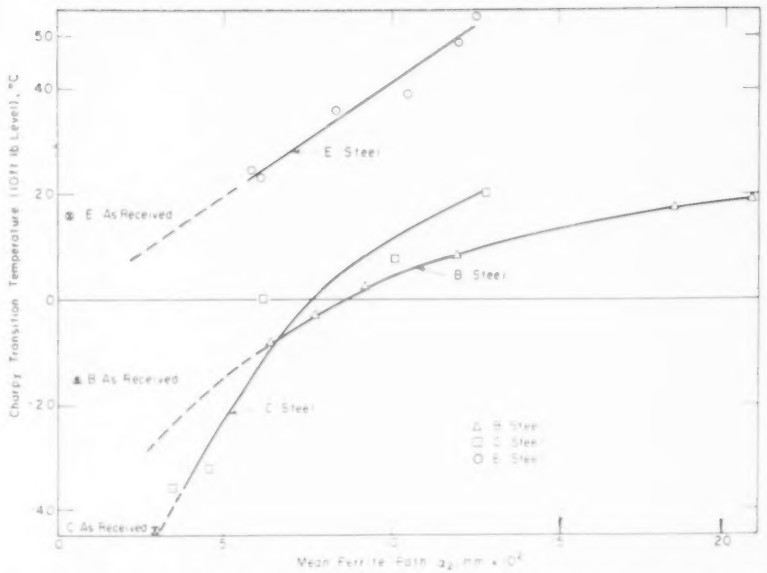


Fig. 10 Charpy transition temperature (10 ft-lb level) as a function of the mean ferrite path α_2. Furnace-cooled series only

For the furnace-cooled series, the E steel transition temperature is about 40° C higher than for the C or B steel of the same ferrite grain size. Two microscopic features of the E steel may contribute to this difference, a 7% increase in the average pearlite volume and the presence of nitride needles in the ferrite. Attempts have been made to assess the proportion of the 40° C change in transition temperature which can be attributed to the pearlite effect. By considering the air-cooled E series, in which negligible changes in ferrite parameters but appreciable variations in pearlite volume with austenitizing temperature are observed, it has been estimated that 1% change in pearlite produces about 0.6° C change in transition temperature. Thus, if it is assumed that this estimate is applicable to the furnace-cooled series, less than 5° C of the 40° C difference can be accounted for by the 7% increase in the volume fraction of pearlite.[22]

Nitrides were found in as-received, air-cooled and furnace-cooled E steel by examination of microspecimens which had

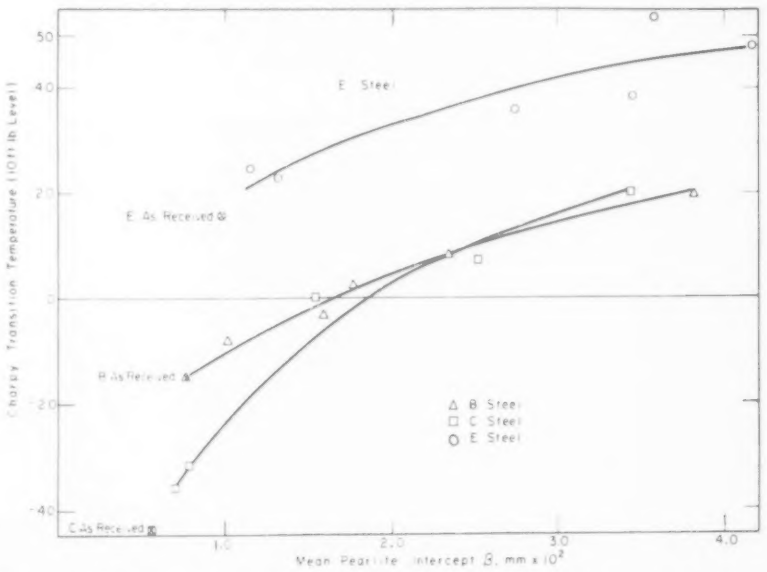


Fig. 11 Charpy transition (10 ft-lb level) temperature as a function of the mean pearlite linear intercept β. Furnace-cooled series only

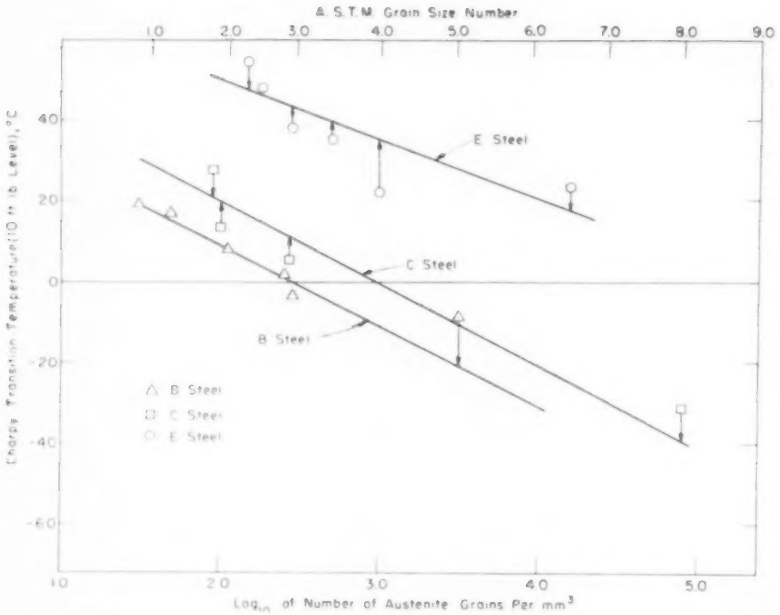


Fig. 12 Relationship between austenite grain size and Charpy transition temperature (10 ft-lb level). Furnace-cooled series only

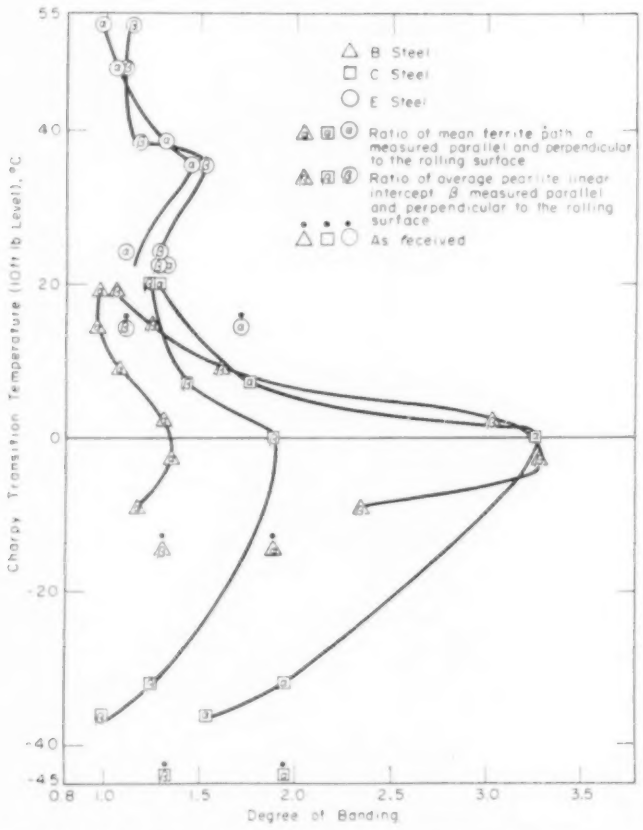
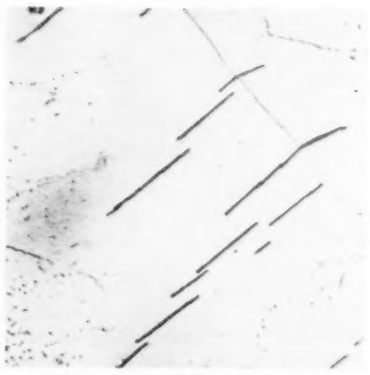


Fig. 13 Charpy transition temperature vs. parameters indicating the degree of banding. Furnace-cooled series only

(a)



(b)

Fig. 14 Microstructure of slowly-cooled E steel showing nitride needles. Electrolytically polished and etched. X 1500 (reduced by $^1/_3$ upon reproduction)

been prepared by electrolytic polishing and etching. Well-developed needles in a slowly-cooled specimen are shown in Fig. 14. The nitrides were highly segregated, although the concentration pattern did not appear to be related to the plate location. For this reason, it was not possible to obtain a significant measure of their volume fraction. An extensive search of C and B steel specimens prepared in the same manner failed to reveal any evidence of nitrides. Due to the lack of quantitative data, no estimate of the magnitude of the effect of nitrides on the transition temperature of the E steel was possible.

Thus, it is evident that the difference in chemistry between the E steel and the C and B steels produces a large difference in the transition temperature which cannot be accounted for by ferrite grain size or pearlite volume effects, but which may be due partially to the presence of nitride needles. However, there is a strong possibility that unknown submicroscopic effects also contribute.

Conclusions

1. Correlations between microstruc-

ture and V-notch Charpy transition temperature exist only when the composition and cooling rate are defined.

2. In annealed structures, the ferrite grain size is the major microstructural parameter determining the transition temperature. The ferrite parameter α_2 and the pearlite parameters seem to have a secondary influence.

3. Ferrite and pearlite banding in annealed structures does not play a major role in the fracture behavior.

4. The transition temperature of annealed specimens shows the same general trend with both austenite and ferrite grain size. However, the correlation with austenite grain size is less significant.

5. Provided the ferrite structure remains equiaxed, increasing the cooling rate from furnace to air cooling decreases the transition temperature, the comparison being made between specimens of the same grain size.

6. When air cooling produces a Widmanstätten structure, the transition temperature is higher than that of a furnace-cooled specimen of the equivalent grain size.

7. The effects produced by changing the cooling rate are partially submicroscopic in origin.

8. Differences in Charpy transition between the killed C steel and semikilled B steel arise primarily because finer structures are produced in the C steel by all treatments in which the maximum temperature is below the coarsening temperature. The rimming E steel has an appreciably greater tendency to brittleness in all conditions, although, when compared at the same ferrite grain size, the difference is minimized by air cooling from 850–950° C. The inferior properties of the E steel cannot be accounted for in terms of the ferrite and pearlite parameters. The effects of this change in chemistry are probably submicroscopic in part but, unfortunately, the situation is complicated by the presence of nitride needles in the E steel which makes impractical any quantitative assessment of the relative magnitude of the microscopic and submicroscopic effects.

Acknowledgments

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RELATIVE BEHAVIOR OF NOTCH-TOUGHNESS TESTS FOR WELDED STEELS

Paper by W. J. Murphy, W. D. McMullen and R. D. Stout appeared in the June 1957 issue of The Welding Journal, 36, Research Suppl., 307-s to 311-s.

DISCUSSION BY W. S. PELLINI and P. P. PUZAK

In their paper, Messrs. Murphy, McMullen and Stout have provided valuable information concerning the relationships of various tests including the drop weight, Kinzel and Charpy V. The discussers are pleased to note that the results are in general agreement with the Naval Research Laboratory (NRL) concepts; our comments are prompted by a desire to clarify and expand on certain of the conclusions rather than by any disagreements with the same.

The statement regarding the requirement of Kinzel test results to be controlled by propagation in the base metal for correlation with the nil ductility temperature (NDT) deserves additional comment because of its basic importance. It should be understood that the weld or heat-affected zone may be quite brittle at a temperature such that the base metal itself is ductile. Under such conditions, the Kinzel test cannot evaluate such zones of brittleness; in other words, the relative quality of these zones may be evaluated only in terms of transition temperatures below the NDT of the base metal. It is for this reason that in our work with weldments of tough steels we choose to evaluate weld or heat-affected zone brittleness by explosion tests featuring biaxial loading (explosion-bulge test). It is sometimes found that a weldment breaks in a brittle manner along the weld or heat-affected zone while the plate resists fracture.

The conclusion concerning correla-

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tion of NDT with Charpy V 10 ft-lb transition appears to present a better case than that which may be assessed when one fully recognizes the spread of the scatterband within which correlation exists. As deduced from previous NRL work, a spread of 75° F (on abscissa) and 50° F (on ordinate) is expected when an invariant value such as 10 ft-lb is taken for correlation purposes. Whereas steels with good notch toughness generally have the NDT appreciably higher than the Charpy V 10 ft-lb transition, the opposite is not always true of steels with relatively poor notch toughness. For example, heavy plates and forgings of A302 and other low-alloy steels may show high transition temperatures and correlation of NDT to values considerably above 10 ft-lb.

The conclusion regarding the effects of postheat treatment on NDT is correct as stated. Here again amplification is required if the significance of the statement is to be fully appreciated. If the heat-affected zone is made more notch tough by welding, as stated by the authors, the test obviously does not work. Such a condition is met, for example, when one attempts to deposit the brittle weld on a quenched and tempered (Q & T) steel of high hardness; here the outer edge of the heat-affected zone is tempered to low hardness and made more notch ductile. Such a problem is not met with conventional quenched and tempered steels used for welding of large structures which are tempered to low hardness (high temperature) so as to develop maximum notch ductility. In our work to establish NDT for high-hardness steels, the crack-starter weld is placed on the specimen before conducting the heat treatment. The A302 retempering effect is, as pointed out, a special case. In the as-welded condition the heat-affected zone is more brittle than the plate (hence corresponds to the equivalent of a wider brittle weld) while in the tempered state a ductile region is developed. Another case requiring caution in the application of the brittle weld relates to heavily cold-worked steels (such as cold-rolled bar stock). Here it is possible to recrystallize the cold-worked metal in the heat-affected zone and thus develop a region of improved ductility. Except for such cases which may readily be rationalized in metallurgical terms, there should be no concern with the effects of the heat-affected zone as long as a stress-relief or tempering treatment is not applied to the test specimens. It should be re-emphasized that *no stress-relief treatment should be given to drop-weight test specimens before testing.*

We have discussed the reasons for NDT being lower on near-static rate loading in THE WELDING JOURNAL, **31** (12), Research Suppl., 561-s to 581-s (1952). Basically, this is the result of stress unloading. The only point of disagreement involves the description of the standard drop-weight test as a propagation test. We rest our case that it is an *initiation* test not only on our analysis of the mechanics involved (THE WELDING JOURNAL, **33** (10), Research Suppl., 481-s to 495-s (1954) and **35** (6), 275-s to 290-s (1956)), but what is more important on numerous correlations with service failures involving initiation areas and propagation areas. In all cases the origin points of the fracture (initiation) were found to be below the temperature defined as NDT while propagation cases have been found above this temperature.

AUTHORS' CLOSURE

The authors wish to thank Messrs. Pellini and Puzak for the interesting discussion presented above and would like to comment briefly on it.

The statement is made by the discussers that the Kinzel test cannot be used to evaluate the notch toughness of the weld or heat-affected zone when these zones are brittle at temperatures such that the base metal itself is ductile. This statement is true if Kinzel test performance is based entirely upon a lateral-contraction transition temperature such as 1% lateral contraction. However, the authors in recent years have relied to a great extent upon analysis of the fracture patterns produced during the failure of Kinzel specimens to supplement lateral contraction measurements. Through such an analysis the quality of the weld or heat-affected zone can usually be evaluated. The use of this technique is reported in THE WELDING JOURNAL, **35** (4), Research Suppl., 169-s to 180-s (1956).

The authors do not feel that the reason for the NDT being lower on near-static tests than on the standard test is stress unloading *per se*. It is believed that this arises from the difference in the amount of energy available to propagate the cleavage crack initiated in the brittle weld metal, this being higher in the case of the dynamic test. Thus for either near-static or dynamic drop-weight tests, the NDT is the temperature below which the cleavage crack initiated in the brittle weld metal can propagate through the entire specimen without changing appreciably to shear. A second important effect is contributed by the reduction of strain rate.

The question as to whether the drop-weight test is an initiation or a propagation test needs clarification. If it is agreed that in this test the base metal is presented with a *running* cleavage crack from the brittle weld metal, then the plastic deformation observed in specimens tested above the NDT can arise only as a result of the inability of the crack to propagate in cleavage. Below the NDT, the crack propagates through essentially the entire specimen in cleavage, thus producing very little plastic deformation. The work done by the authors further substantiates the viewpoint that the drop-weight test is a propagation test. Examination of the fracture surfaces of specimens tested in the absence of the "stop" which limits total deflection to 0.3 in. reveals that just above the NDT the cleavage crack after entering the base material changes to shear along the entire crack front, and that complete failure of the specimen is a result of the "forcing" of the shear crack through the remainder of the specimen.

The reason that the NDT correlates with service failures involving the initiation areas is a result of the fact that cleavage cracks cannot initiate in areas through which they cannot propagate.

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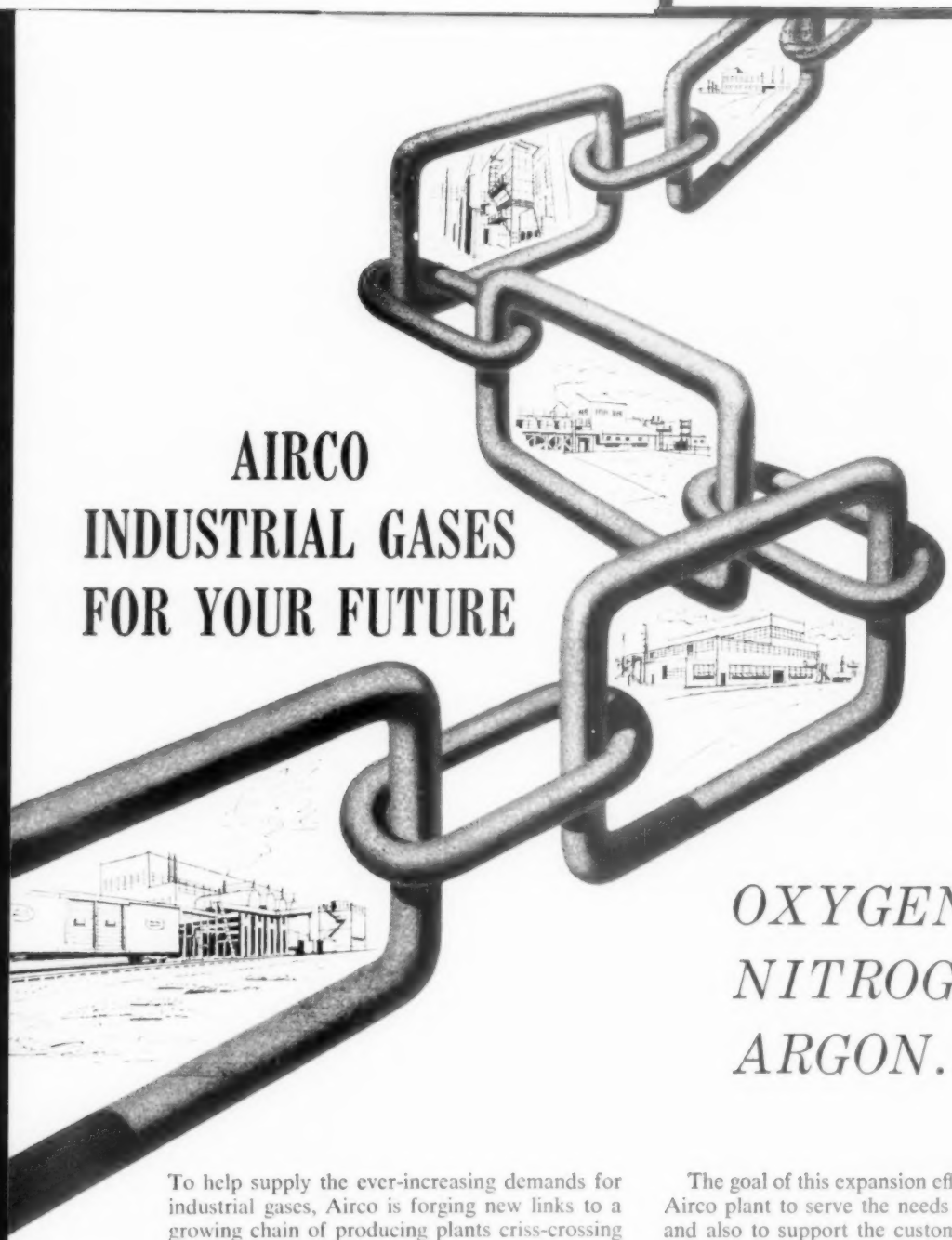

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